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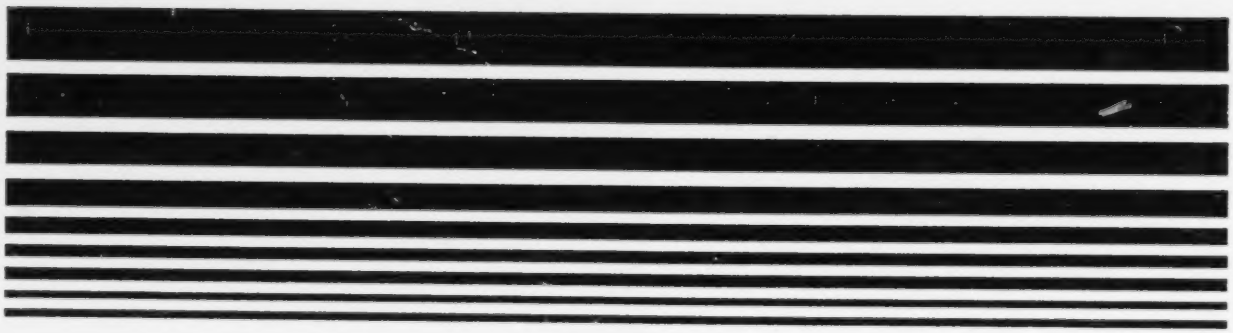

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CONSIDERATION OF TRANSPORTED OZONE AND PRECURSORS AND THEIR USE IN EKMA

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16. ABSTRACT

This document describes how to account for transport of ozone or ozone precursors when using the Empirical Kinetic Modeling Approach (EKMA) or the Urban Airshed Model (UAM).

Appendix A describes how to apply a Personal Computer (PC) computer program to determine backtrajectories using surface wind data.

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PREFACE

This document is one of five related to application of EKMA and the use of OZIPM-4 (Ozone Isopleth Plotting with Optional Mechanisms), the computer program used by EKMA. Listed below are the titles of the five documents and a brief description of each.

"Procedures for Applying City-specific EKMA", EPA-450/4-89-012, July 1989

- Describes the procedures for using the Empirical Kinetic Modeling Approach (EKMA). The major focus is on how to develop needed inputs for OZIPM-4. In addition this document describes how to determine a control target once OZIPM-4 has been run.

"A PC Based System for Generating EKMA Input Files", EPA-450/4-88-016, November 1988

- Describes a program that creates EKMA input files using a menu driven program. This sofware is only available for an IBM-PC or compatible machine. Files built using this system can be uploaded to a mainframe computer.

"User's Manual for OZIPM-4 (Ozone Isopleth Plotting with Optional Mechanisms)-Volume 1", EPA-450/4-89-009a, July 1989

- Describes the conceptual basis behind OZIPM-4. It describes the chemical mechanism, Carbon Bond 4, and each of the options available in OZIPM-4. Formats for each of the options are outlined so that a user can create input files using any text editor.

"User's Manual for OZIPM-4 (Ozone Isopleth Plotting with Optional Mechanisms)-Volume 2: Computer Code", EPA-450/4-89-009b, July 1989

- Describes modifications to the computer code that are necessary in order to use OZIPM-4 on various machines. A complete listing of OZIPM-4 is also found in this publication.

"Consideration of Transported Ozone and Precursors and Their Use in EKMA", EPA-450/4-89-010, July 1989

- Recommends procedures for considering transported ozone and precursors in the design of State Implementation Plans to meet national ambient air quality standards for ozone. A computerized (PC) system for determining whether an ozone exceedance is due to overwhelming transport is described. This document is necessary, only if an area is suspected of experiencing overwhelming transport of ozone or ozone precursors.

EKMA may be used in several ways: (1) as a means for helping to focus more resource-intensive photochemical grid modeling analyses on strategies most likely to be successful in demonstrating attainment; (2) as a procedure to assist in making comparisons between VOC and NOx controls; (3) in non-SIP applications, such as in helping to make national policy evaluations assessing cost/benefits associated with various alternatives and (4) for preparation of control estimates consistent with limitations/provisions identified in Clean Air Act Amendments.

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EXECUTIVE SUMMARY

This report recommends procedures for considering transported ozone (O_3) and precursors when using the Empirical Kinetics Modeling Approach in the absence of regional scale modeling data. Incidents of high O_3 near a metropolitan statistical area (MSA) are categorized according to whether or not "overwhelming transport" of ozone/precursors has occurred. Overwhelming transport happens when high O_3 is primarily attributable to emissions in MSA's further upwind than the MSA under review. This determination is made using hourly surface wind data to construct a back trajectory originating at the site and time of an observed O_3 incident. Ordinarily, if the trajectory suggests that the air reaching a monitor at the time of observed high O_3 was over the local MSA between 8 a.m. - noon, local emissions are assumed to be significant. Otherwise, overwhelming transport is assumed.

If overwhelming transport is identified and EKMA is used*, the back trajectory should be examined to identify potentially culpable MSA's. These would be located in a zone defined by that portion of the trajectory corresponding with 8 a.m. - noon. If projected controls in the identified MSA(s) are sufficient to reduce O_3 to $\leq$ 0.12 ppm, the incident of overwhelming transport may be ignored in the attainment demonstration for the downwind (local) MSA. If it cannot be demonstrated that upwind controls are sufficient to reduce an incident of overwhelming transport to O_3 levels $\leq$ 0.12 ppm, the local control target in the downwind MSA is raised. This is <u>not</u> done by

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*Under proposed legislation (HR3030), use of EKMA as a means to demonstrate attainment of the ozone NAAQS resulting from a SIP would require a prior determination that EKMA is likely to yield predictions having similar validity to those obtained with a grid model.

modeling the incident with EKMA in the local attainment demonstration. Instead, the incident is treated as an "irreducible exceedance." In attainment demonstrations with EKMA, it is necessary to show that the expected number of occasions per year on which daily maximum O_3 is > 0.12 is $\leq$ 1.0. Ordinarily, a 3-year period is considered. Hence, if the fourth highest control estimate is met, this means there would only be three occasions with daily maximum at a site > 0.12 ppm over a 3-year period. Thus, if the control target needed to meet the NAAQS were ordinarily the fourth highest control estimate, with the irreducible exceedance it would become the third highest estimate.

It is likely that, in most locations, for the majority of occasions high O_3 will not be judged to be a product of overwhelming transport. In these cases, transport is treated by specifying boundary conditions to the urban scale models. These boundary conditions represent pollutants advected into the modeling domain as a result of a mix of single- and multi-day transport. The following transported pollutants may be considered by existing models: O_3, nonmethane organic compounds (NMOC), mix of organic species comprising NMOC, oxides of nitrogen (NO_x), portion of NO_x which is nitrogen dioxide (NO_2), and carbon monoxide (CO).

Use of upwind surface air quality monitors meeting certain siting criteria is recommended for estimating present boundary conditions for O_3, NO_x, and NO_2. In the event these monitors are unavailable for NO_x/NO_2, default values are also recommended for EKMA. Since upwind measurements of NMOC and its component species are unlikely to be available, default recommendations are provided for these as well. Default recommendations are based on monitoring studies

conducted upwind of several cities in 1985 and 1986 using aircraft. The effect of CO transported intercity can ordinarily be ignored.

To completely assess the role of transport, it is necessary to project future boundary conditions. It is here where the results of regional scale ozone modeling are most needed. However, for locations where regional model predictions are not available, default recommendations for O_3, NO_x/NO_z and NMOC (NMOC species) are provided. These are based on model simulations including the effect of nationally mandated controls on volatile organic compound (VOC) and NO_x emissions, natural background, and the estimated impact such controls might have on O_3 at the end of a single day's travel time. In the absence of regional modeling results or compelling evidence to the contrary, it is recommended that default assumptions concerning future boundary conditions be used for consistency.

The procedure to calculate back trajectories has been developed as a spreadsheet which will run on an IBM-PC (or compatible machine). Guidance on how to use this program is contained in Appendix A.

1.0 INTRODUCTION

Much controversy has arisen in recent years abc consider transport of O_3 and precursors from city to city in regulatory strategies. The fundamental concern is, ho which are equitable as well as effective? Both politica and scientific/economic issues bear on the solution tc example, certain strategies may not be feasible because with existing laws or with a Federal system of governmen illegal, require convincing scientific and/or economic just political obstacles. This may include a demonstration tha an area are likely to affect ozone within or downwind of relative importance of pollution transported from upwind, e locally generated emissions is an important part of such a

1.1 Purpose

The purposes of this report are:

(1) to provide a comprehensive set of recommendat transport using EKMA in the absence of regional modeling re provide a rationale and other information supporting the re

1.2 Organization

The remainder of this paper is organized in the follow Section 2.0 presents an overview of two basic scenarios transport. These differ in the degree to which transport first is termed, "overwhelming transport." The second addre which local emissions, along with transport, have a sign observed O_3 concentrations. Section 3.0 is an in-depth dis

identify overwhelming transport and potentially culpable upwind MSA's or consolidated metropolitan statistical areas (CMSA). Section 4.0 describes how to estimate boundary conditions. Specification of boundary conditions is the way in which transport is considered on days when local emissions are important contributors to observed O_3.

2.0 OVERVIEW: TWO TRANSPORT SCENARIOS

2.1 Overwhelming Transport

Overwhelming transport occurs when it is likely that contributions of local emissions to observed/predicted O_3 is minor. Putting this another way, local emissions could be completely eliminated and there would be little, if any, effect on the observed or predicted daily maximum O_3 concentration. It is fruitless to develop a local control strategy based on such an incident. Yet, the goal of a SIP is to demonstrate that each local control strategy is adequate to attain the NAAQS, even at locations subject to overwhelming transport. The procedure outlined in the following paragraphs may be used to resolve this seeming inconsistency.

Demonstrating attainment in or near MSA's subject to possible overwhelming transport entails a four-step procedure.

Step 1. Assess the likelihood that an observed ozone concentration is influenced by local emissions. This is done primarily through the use of surface wind data, timing of an observed exceedance, and orientation of a monitor with respect to the MSA under review. The foregoing information is used to construct a backward trajectory from an O_3 monitoring site. A band of uncertainty is assigned to this trajectory based on variability of recorded wind directions. Figure 1 presents a conceptual picture of the results. If ozone

air quality data exist upwind from the MSA, these data may also be used to refine estimates obtained using wind data alone. Detailed analyses to perform this step are described in Section 3.0.

Step 2. Assign the incident to the upwind MSA most likely culpable. The analysis in Step 1 will identify a fairly broad geographical region. This region is one where an air parcel reaching an O_3 monitor at the time of an observed high concentration is most likely located during the time of day having high emissions subject to several hours of meteorological conditions conducive for O_3 formation (i.e., 8 a.m. - noon, LDT). If the local MSA is included within the identified geographical region, the incident in question is not considered to be a case of overwhelming transport. If the local MSA is excluded, the identified geographical area is searched for other, upwind MSA's. Generally, if one MSA/CMSA is much larger in terms of emission rates than any other in the identified region, it is selected as the most likely culpable source of the O_3 observed downwind. The SIP covering the identified culpable MSA/CMSA should demonstrate that projected controls are sufficient to reduce the level of O_3 observed downwind on the incident in question to $\leq$ 0.12 ppm. If the SIP for the culpable MSA/CMSA shows that it is sufficient to reduce higher O_3 concentrations than that observed downwind to $\leq$ 0.12 ppm under several sets of meteorological conditions, this should ordinarily suffice.

It may sometimes happen that there are several MSA's within the identified region, all of which are about the same size. In such cases, it may not be possible to single out one culpable upwind MSA. An alternative for dealing with this situation is to review SIP's for each to assure projected controls in each

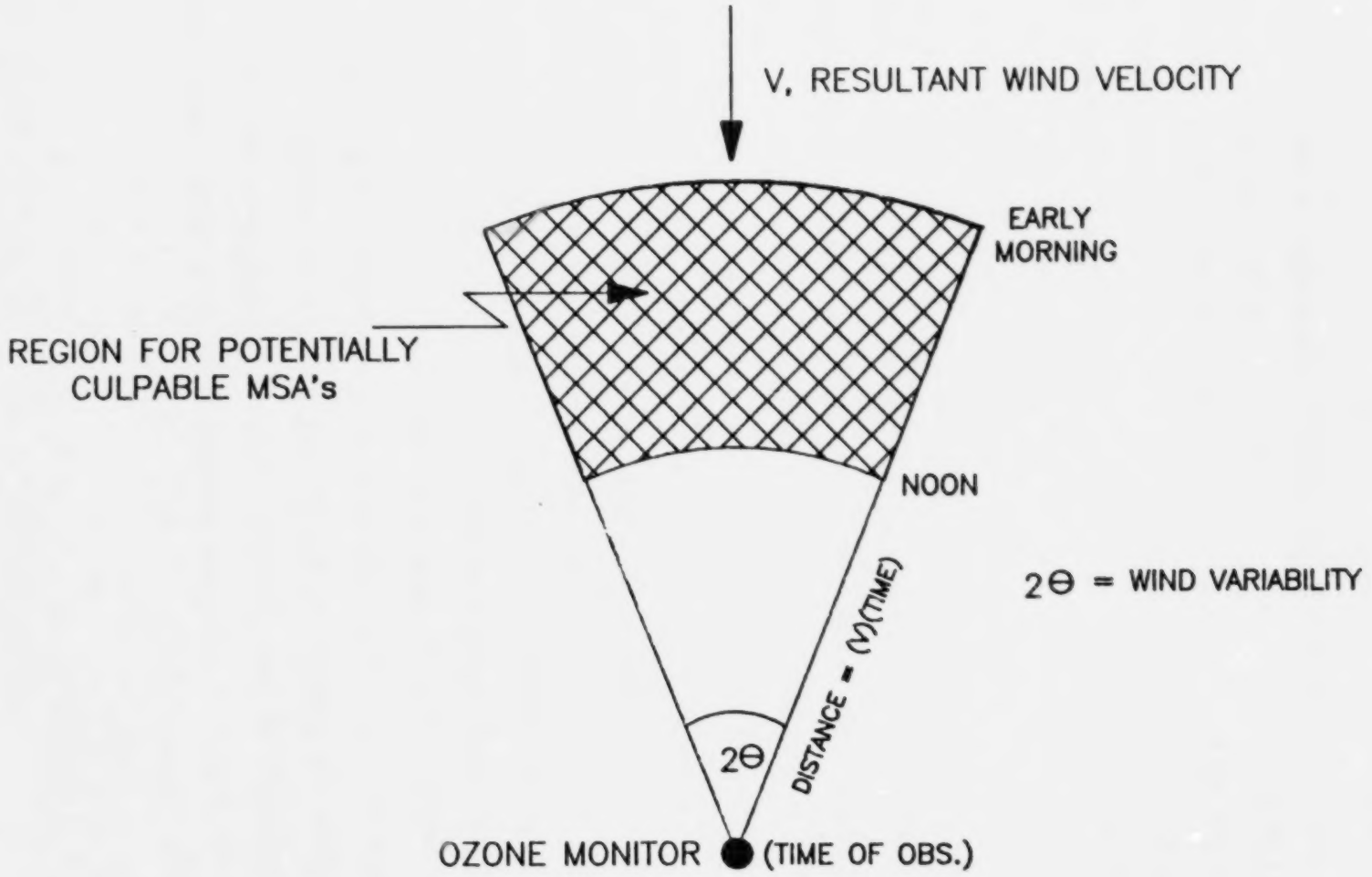


FIGURE 1. DETERMINING OVERWHELMING TRANSPORT CONCEPTUAL VIEW

MSA would be sufficient to reduce O_3 downwind to $\leq$ 0.12 ppm during the incident being reviewed.

Step 3. Tighten local controls if upwind culpability cannot be established. Several undesirable outcomes, from the viewpoint of the downwind MSA, might result from Step 2. First, the large identified culpable MSA/CMSA may be able to demonstrate attainment without reducing O_3 in the downwind MSA to $\leq$ 0.12 ppm on the incident in question. For example, this could happen if three valid years of data existed at the downwind site and the incident was one of three occasions attributable to the upwind MSA where 0.12 ppm could be exceeded over the 3-year period. Recall that the NAAQS is met if the expected number of daily maximum O_3 concentrations > 0.12 ppm is less than or equal to 1.0/year. Another undesirable outcome could be that the methodology to be described in Section 3.0 is unable to identify any candidate culpable MSA's.

If either of the outcomes described in the previous paragraph occur, it will be necessary to raise the local control target. In this case, the incident of overwhelming transport is treated as an "irreducible exceedance" in the procedure to establish a control target for the local MSA. Ordinarily, an MSA having O_3 monitors with three valid years of observed daily maxima would choose the highest fourth highest site-specific control estimate as its control target (USEPA, 1989a). Now, however, with one exceedance which is assumed to be unaffected by local controls and for which no commitment is made by upwind MSA's to eliminate the problem, we must presume that similar incidents will persist at approximately the same frequency. Thus, the control target derived with EKMA becomes the highest third highest site-specific control target. Table I presents

the appropriate local target as a function of the number of "irreducible exceedances."

Step 4. If necessary, include consideration of "secondary peaks" on days with daily maxima resulting from overwhelming transport. Occasionally, there may be two periods during a day in which O_3 > 0.12 ppm is observed at a monitoring site. On days subject to overwhelming transport, the following example is possible: high O_3 around noon or early afternoon, followed by lower concentrations in mid-afternoon and highest concentrations in late afternoon or early evening. Suppose it were determined that the late afternoon (maximum) values were the likely product of overwhelming transport, but that local emissions most likely contributed to the earlier excursions above 0.12 ppm. How would such a situation be addressed? The overwhelming transport incident (i.e., late afternoon in this example) would be handled exactly as described in Steps 2 and 3 above. Local control estimates addressing the secondary (early afternoon) peak would be made exactly as they would for any other day (USEPA, 1989a; USEPA, 1989b). If the incident of overwhelming transport is treated as an "irreducible exceedance," the problem causing the earlier peak can usually be ignored. It has already been conceded that local controls will not be able to reduce all O_3 observations on this day to $\leq$ 0.12 ppm. An exception to this would occur if there were four or more "irreducible exceedances" at a monitoring site (assuming three valid years of observations). Here, the site-specific control estimate would be the highest control estimate obtained considering all days (with or without overwhelming transport) for which local emissions are

TABLE I

LOCAL CONTROL TARGETS AS A FUNCTION OF UNEXPLAINED INCIDENTS OF OVERWHELMING TRANSPORT*

NUMBER OF UNEXPLAINED EXCEEDANCES	LOCAL CONTROL TARGET TARGET
0	Highest fourth high site-specific estimate
1	Highest third high site-specific estimate
2	Highest second high site-specific estimate
≥ 3	Highest site-specific estimate

*Table assumes all sites have 3 years of valid data.

believed to contribute to a daily maximum O_3 concentration or to a secondary peak.

2.2 Days Without Overwhelming Transport

For most areas of the country, "overwhelming transport" is likely to be relatively unusual. That is, most of the time emissions in the nearest MSA are likely to be an important factor leading to high observed O_3. Local control strategies are ordinarily designed by determining what is necessary to reduce O_3 in the urban plume to $\leq$ 0.12 ppm. Then, depending on such factors as data completeness and presence of "irreducible exceedances," a control strategy demonstrating attainment is selected.

In the foregoing procedure, transport is considered in the form of boundary conditions. Boundary conditions are specified as pollutant concentrations advected into the modeling domain. These specifications are multidimensional. That is, they cover:

- four pollutants (O_3, NMOC, NO_x, and CO);
- $\geq$ 2 altitudes (in the morning mixed layer and above the morning mixed layer but below the maximum afternoon mixing height);
- two time periods (base period and the future or projected period);
- compositional assumptions for two pollutants (mix of NMOC species and portion of NO_x which is NO_2).

Figure 2 summarizes boundary conditions considered in an application of city-specific EKMA. Thus, the effect of transport is considered by estimating present concentrations of O_3, NMOC, NO_x, and CO advected into the modeling domain and then projecting future concentrations of these transported pollutants.

Procedures for doing this are described in Section 4.0, as is use of this information to derive control targets.

3.0 IDENTIFYING OVERWHELMING TRANSPORT

3.1 Data Bases

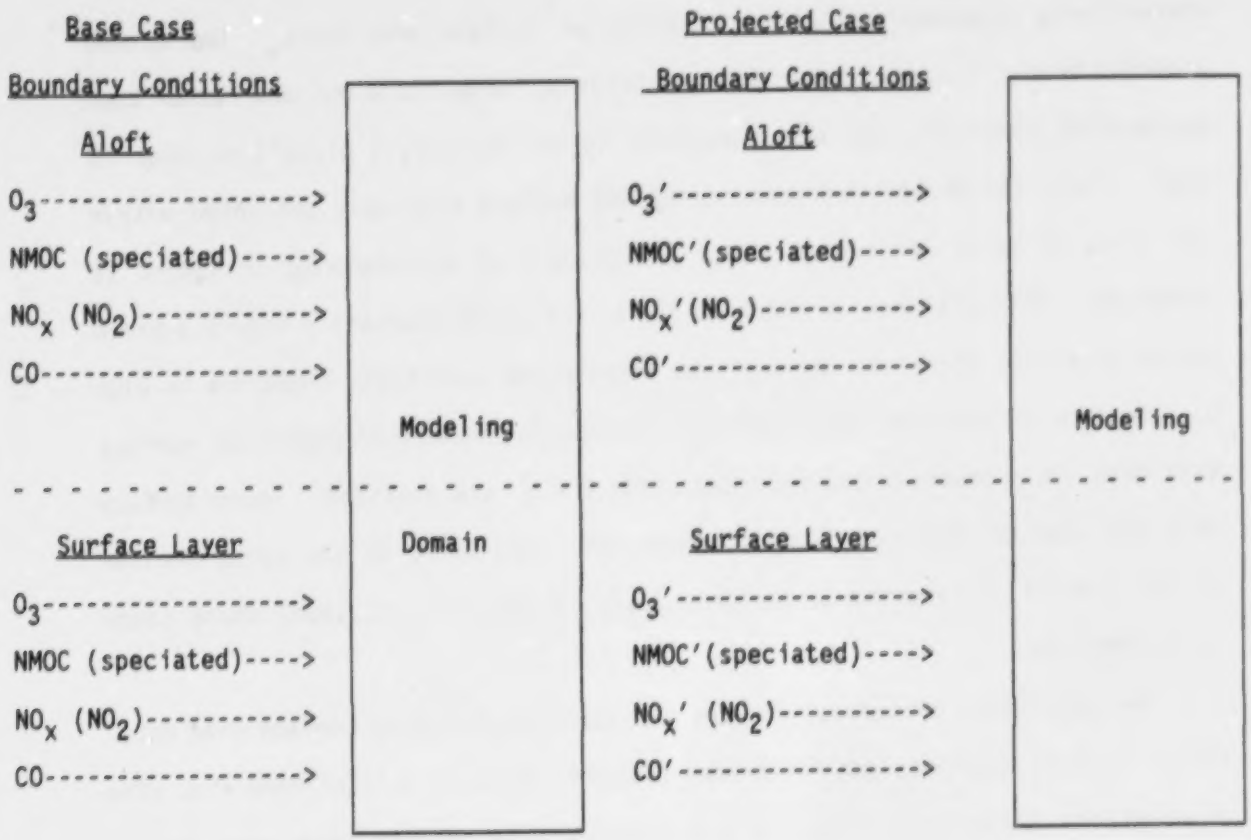
There are three potential sources of information which could be utilized to assess whether an incident of high O_3 is a product of overwhelming transport:

- surface wind data
- upper air wind data
- surface ozone observations

Surface wind data are typically measured about 2m above the ground at National Weather Service (NWS) stations. Observations of these measurements are made at hourly intervals. However, these hourly observations are only archived for a subset of NWS stations. These sites are identified in Appendix B (Hatch, 1983). Upper air measurements are made at about 50 sites (in the order of 300 miles apart) twice a day (0700-0800 EDT and 1900-2000 EDT). Like surface observations, upper air measurements at any reported altitude are made over very short (nearly instantaneous) time periods. Ozone observations are made continuously at surface monitoring sites. Resulting continuous traces at each site are integrated over hourly intervals to archive hourly average O_3 concentrations. Because of normal diurnal patterns in atmospheric stratification, surface deposition, and chemical reactions between ozone and scavenging species, surface measurements made several hours before and after as well as during nighttime may not be representative of transported ozone. Also, surface wind measurements at night represent the local flow regime near the

FIGURE 2

BOUNDARY CONDITIONS DEPICTING TRANSPORT



ground close to the measurement site. Therefore, use of surface data is limited to daytime measurements.

3.2 Use of Data

The procedures to be suggested in this paper for identifying cases of overwhelming transport rely most heavily on surface wind data. The method proposed herein is concerned with characterizing large scale motions rather than documenting precisely the exact position of an individual plume from hour to hour. Thus, the method utilizes hourly NWS surface wind data collected within 100 miles of an O_3 monitor at which an incident of overwhelming transport is suspected. This distance is about as far as one would ordinarily expect a given parcel of air to travel during daylight hours under conditions conducive to high O_3. Because of concerns over vertical representativeness of nighttime surface wind data, only observations recorded after 8 a.m. are utilized. These surface data are used to construct back trajectories originating at the ozone monitor at the time of an observed O_3 incident (usually the daily maximum) whose cause is in question.

Two additional considerations are necessary in utilizing surface wind data. Due to surface roughness and frictional effects, there is a likelihood that wind observations measured at 2 meters may underestimate typical wind speed within the surface mixed layer. Using information presented in U.S. EPA (1988b), we have estimated these surface winds could underestimate average wind speed within a typical daytime mixed layer by as much as a factor of "2." There is a second consideration, however, which makes such a large underestimate of travel distance computed with surface data unlikely. Recall that "hourly" wind data are actually observations made over about 1 minute. If this information is used to estimate

travel distance during the hour, the estimate would probably be too high. It is unlikely that a 1-minute observation would persist without deviation in wind direction or speed over the entire hour. This is particularly true for low wind speeds. The foregoing suggests that observed surface wind speeds may, perhaps, need to be adjusted upward by some amount, but by less than a factor of "2."

To arrive at a suitable surface wind adjustment factor, we have computed adjustment factors based upon wind profile exponents and typical stabilities and elevations. We then examined a subset of high ozone incidents observed in Connecticut and Massachusetts during June-August 1983. Because there is a relatively dense network of O_3 monitors, it is possible to "track" an ozone plume moving from western to northern or eastern Connecticut or to central Massachusetts on the selected incidents. If an adjustment factor of "1.5" is applied to the surface wind data, close correspondence between a plume originating in the large New York CMSA during critical times of day and highest observed O_3 is observed. Use of this "1.5" factor, as well as the methodology in general, was later tested against other incidents of high ozone observed in Connecticut/Massachusetts during summer 1983. As described in Section 3.6, reasonable agreement was found between air quality observations and estimated trajectories with this factor.

3.3 Computing Back Trajectories

In assessing the likelihood of overwhelming transport, we are interested in two things: (a) the net distance a pollutant-laden air parcel has traveled to reach an end point at a prescribed time and (b) a measure of the variability in the pathway followed in traversing this net distance. For these a back trajectory originating at the time and location of an O_3 observation under

question is calculated to establish whether or not overwhelming transport is likely. Prior to describing the procedure for doing so in detail, it is necessary to distinguish between wind velocity (V) and wind speed (v). Wind velocity is a vector quantity consisting of both speed and direction (φ). The wind speed is a scalar (1-dimensional) quantity. In order to estimate the path traveled by an air parcel over a time, t, it is necessary to consider both of these components. Procedures for calculating back trajectories are described in this section. Figure 3 illustrates the difference in wind velocity and wind speed.

3.3.1 Estimating Distance Traveled

For any time period t, net distance traveled is given by

$$d = \bar{V}t \tag{1}$$

d = miles traveled

$\bar{V}$ = resultant wind velocity over time t, mph

t = time, hours

If observations at several sites are weighted equally, the average resultant wind velocity during the period t is given by

$$\bar{V} = \sqrt{\frac{1}{n}\left(\left[\sum_{i=1}^{n} (\text{easterly component})_i\right]^2 + \sum_{i=1}^{n} (\text{northerly component})\right]_i^2)} \tag{2}$$

where n = number of sites

$$(\text{easterly component})_i = (v_i)(\text{SIN}\varphi_i) \tag{2a}$$

$$(\text{northerly component})_i = (v_i)(\text{COS}\varphi_i) \tag{2b}$$

v_i = average wind speed measured at site i during period t

φ_i = wind direction at site i, varying from 0 - 359° $\varphi = 0°$ means wind is <u>from</u> the north, $\varphi = 90°$ means wind is <u>from</u> the east, etc.

One refinement is made to Equation (2). It seems reasonable to weigh wind observations made nearby more heavily than those which are made at greater distances. This is commonly done by weighing observations according to the inverse square of their distance from the location of interest ($1/R^2$). We follow this convention. Therefore, Equation (2) becomes

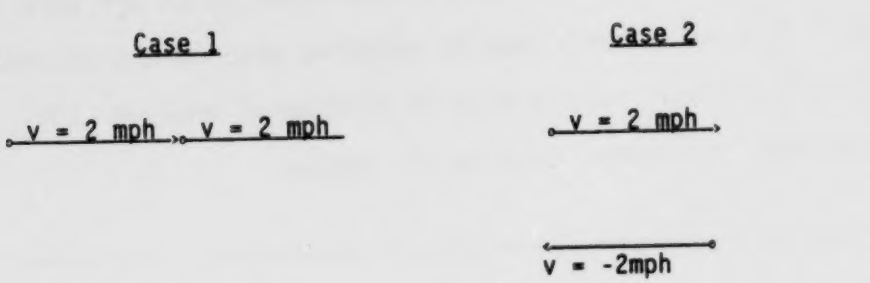
$$V_t = \sqrt{\left(\sum_{i=1}^{n} \frac{1}{1/R_i^2} \left[\sum_{i=1}^{n} \frac{1}{(R^2)_i} (\text{easterly})_{it} \text{ component}\right]\right)^2 + \left(\sum_{i=1}^{n} \frac{1}{R_i^2} \left[\sum_{i=1}^{n} \frac{1}{(R^2)_i} (\text{northerly})_{it} \text{ component}\right]\right)^2} \quad (3)$$

3.3.2 <u>Estimating Direction and Variability in Pathway Traveled</u>

The direction traveled by a parcel during a time period t is simply the mean wind direction derived by weighing wind observations according to the inverse square of their distances from the trajectory's starting point at t. This is given by Equation (4).

$$\bar{\varphi}_t = \cos^{-1}\left[\frac{\sum_{i=1}^{n} \frac{1}{1/R_i^2} \left[\sum_{i=1}^{n} \frac{1}{(R^2)_i} (\text{northerly component})_i\right]}{\bar{V}}\right]_t \quad (4)$$

FIGURE 3. ILLUSTRATING DIFFERENCE BETWEEN WIND VELOCITY AND WIND SPEED



$\bar{V} = \frac{2 + 2}{2} = 2$ mph

$v = \frac{2 + 2}{2} = 2$ mph

$\bar{V} = \frac{2 + (-2)}{2} = 0$ mph

$v = \frac{2 + |-2|}{2} = 2$ mph

where $\bar{V}_t$ is the magnitude of the mean resultant wind velocity derived from Equation (3) for period t, i, n, R_i are defined in Equations (2) and (3).

Variability or uncertainty in the direction of an estimated trajectory is determined using wind direction data (φ_i), and by comparing average resultant wind velocity (V_t) with average wind speed (v_t).

For each time period, t, we define a wind variability angle (θ) using Equations (5) or (6).

$$2\theta = \cos^{-1}\left[\frac{\bar{V}}{\sum_{i=1}^{n}\frac{1}{1/R_i^2}\ \sum_{i=1}^{n}\frac{1}{(R_i^2)}\ (v_i)}\right]_t \qquad (5)$$

or

$$2\theta = \cos^{-1}\left[\frac{\bar{V}_t}{\bar{v}_t}\right] \qquad (6)$$

where V_t = mean weighted resultant wind velocity for period t (from Equation (3))

v_t = mean weighted wind speed for period t

For a single time period, "2θ" is shown in Figure 1. The angle 2θ is bisected by the weighted average wind direction ($\bar{\varphi}$) computed for period t.

3.3.3 Estimating Trajectories for Consecutive Time Periods

We have seen, in Section 3.3.1, how to estimate distance covered by a back trajectory during a single time period t. In Section 3.3.2, we have also shown how to estimate the direction and variability associated with the trajectory during period t. The time steps considered in these analyses are an hour in length. Therefore, it is necessary to repeat the procedure described in Section 3.3.1 and 3.3.2 for several hours, beginning at the time and location of the observed O_3 concentration being assessed and ending at 8 a.m. LDT. In repeating these calculations, note that the distances between the trajectory starting point for a given hour and the wind monitors (R_i) are different at the beginning of each time period. Of course, the values for wind speed (v_i) and direction (φ_i) also change for each new time period. Conceptually, a back trajectory computed for several hours would look like that shown in Figure 4.

3.4 Example Calculations for Back Trajectory Estimates

Section 3.3 presents the following procedure for estimating back trajectories with surface wind data.

1. Begin the back trajectory at ozone monitoring site at the time of the O_3 observation being evaluated (e.g., 2 p.m.).

2. Calculate northerly and easterly components of wind velocity at t = 0 (e.g., 2 p.m.) at each NWS wind monitor within 100 miles of the ozone monitor using Equations (2a) and (2b).

3. Calculate weighted average resultant wind velocity $\bar{y}$ (V) for t = 0 using Equation (3).

4. Calculate weighted mean wind direction $\bar{\varphi}$ (φ) for t = 0 using Equation (4).

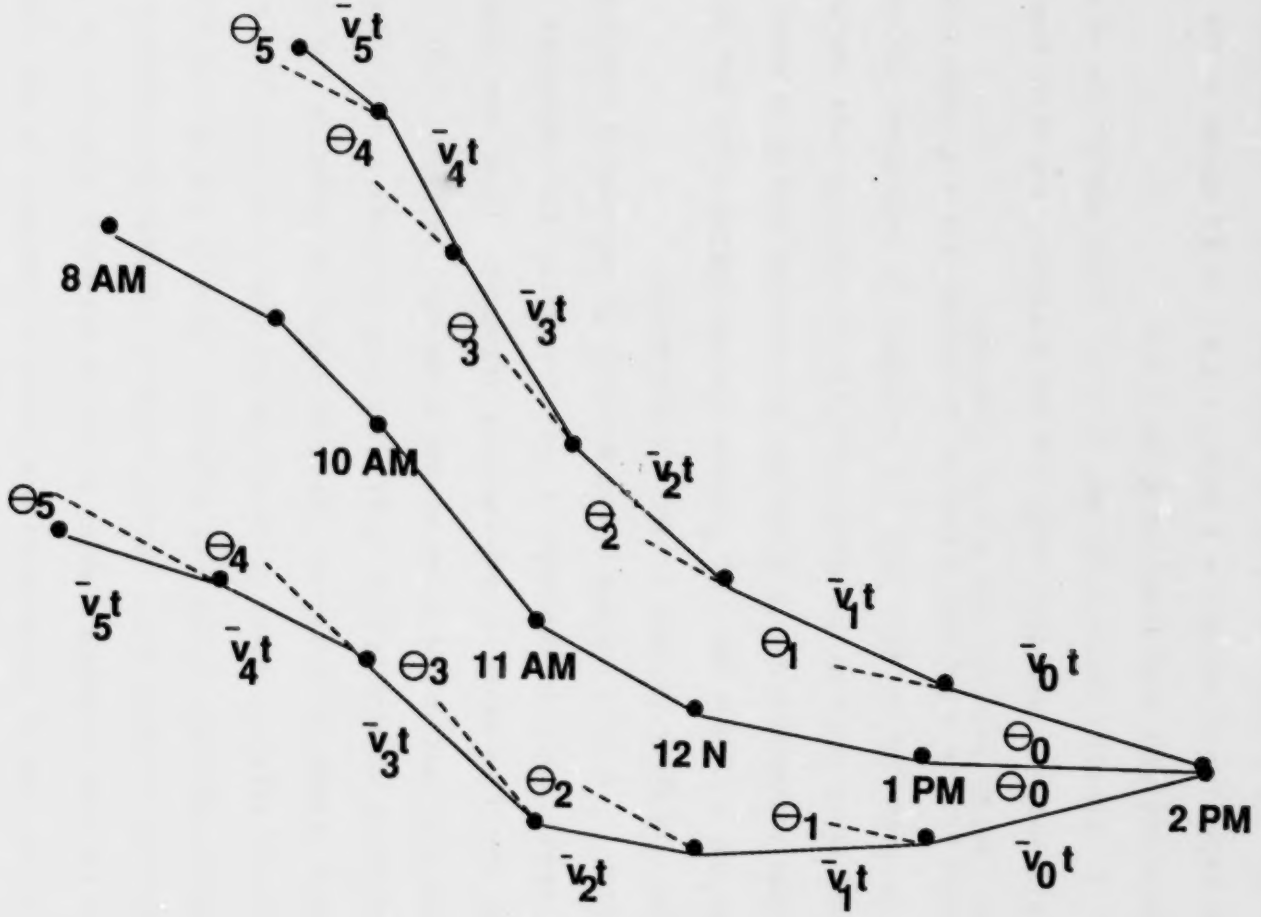


Figure 4 - Multiperiod Back Trajectory Conceptual View

5. Estimate wind direction variability (2θ) for t = 0 using Equations (5) or (6).

6. The distance traveled in first hour is $\bar{V}_0 t$. The new starting point for beginning of period t = 1 (e.g., 1 p.m.) is $\bar{V}_0 t$ upwind in the direction of the mean wind direction $\bar{\varphi}_0$ for t = 0.

7. Consider the next period, (t + 1). Enter appropriate values for $(R_i)_{\bar{t+1}}$, $(\varphi)_i$, and $(v_i)_1$ and repeat steps 2-6 for trajectory end point from last hour. Repeat process until 8 a.m. is reached.

Several of the equations presented in Section 3.3 are cumbersome. An example is presented to make sure the procedure is understood correctly. A spreadsheet which performs the actual calculations has also been prepared and is described in Appendix A. In actuality, all the user need do is enter hourly wind data and locations for 3-10 surface wind monitoring sites and the ozone monitoring site where the back trajectory originated.

Example 1: A daily maximum O_3 concentration is observed at 3:00 p.m. EDT. A State agency wants to determine a back trajectory for subsequent use in assessing the likelihood of overwhelming transport. There are three wind monitoring sites within 100 miles of the O_3 monitor. Initially, site 1 is 10 miles from the O_3 monitor, site 2 is 30 miles away, and site 3 is 50 miles away.

Several mandatory procedural features should be noted in the example. First, careful attention needs to be paid to the sign (+ or -) of the northerly and easterly components of the wind velocity. Ignoring a minus sign will lead to an incorrect estimate of φ. Second, Equation (4) does not provide a unique value for the wind direction. Which of the two potential solutions is correct depends on the sign of the weighted mean easterly component for the wind

velocity. If this is positive, the smaller of the two calculated values for ϕ_i applies. These checks are automatically made in the spreadsheet program. Third, as discussed in Section 3.2, remember to use the adjusted wind speed. Finally, make sure wind speed, velocity, and time increments are expressed in consistent units.

3.5 Using a Calculated Back Trajectory to Identify Potentially Important Sources of Observed Ozone

Once a back trajectory has been constructed as described in the preceding section, the next step is to use the resulting information to identify most likely locations for emissions having a major effect on the observed O_3 value being evaluated. Our suggested methodology maintains that emissions between the morning rush hour (i.e., 8 a.m. LDT) and noon LDT are likely to be very important in leading to observed high O_3. This allegation is based on two beliefs. First, diurnal emission patterns for VOC and NO_x are likely to produce a disproportionately large amount of emissions during this period. Second, and perhaps more importantly, meteorological conditions during this time of day and shortly thereafter are most opportune for high O_3 to form. That is, the sun will shortly reach its zenith, temperatures are high and, in the beginning of the period, dilution is relatively poor. Since it takes several hours after emissions of precursors for O_3 to reach maximum potential, 0800-1200 emissions should make a disproportionately large contribution to high observed O_3. If the calculated back trajectory is not consistent with 0800-1200 local emissions making a contribution, an observed O_3 level may be a product of overwhelming transport.

There is an exception to the preceding rule of thumb. This occurs, because routinely used anemometers cannot measure light winds reliably. Winds $\leq$ 2 mph

The following data are observed:

Input - Example 1

t	Time	Wind Site i	Wind Speed (v_i) (mph)	Adjusted Wind Speed (mph)	Adjusted Wind Direction (φ_i)
0	1500	1	4	6	260
		2	3	4.5	240
		3	5	7.5	180
1	1400	1	5	7.5	250
		2	6	9	230
		3	6	9	190
2	1300	1	6	9	230
		2	6	9	240
		3	6	9	200
3	1200	1	5	7.5	230
		2	5	7.5	240
		3	5	7.5	200
4	1100	1	4	6	240
		2	5	7.5	230
		3	4	6	190
5	1000	1	3	4.7	240
		2	3	4.7	220
		3	3	4.7	200
6	0900	1	4	6	230
		2	3	4.7	220
		3	3	4.7	200
7	0800	1	2	3	220
		2	2	3	210
		3	2	3	190

may not exert sufficient force, on NWS instruments, to overcome inertia (USEPA, 1987c). Thus, the following exception applies:

> If the magnitude of the mean average resultant wind velocity occurring between 8 a.m. and the time of the observed O_3 is $\leq$ 3 mph, it should be assumed that local emissions are important factors leading to observed high ozone.

Magnitude of the mean average resultant velocity is determined by noting the straightline distance between the centerline of the back trajectory at 0800 LDT and the O_3 monitoring site and dividing this distance by the number of hours between 0800 and time of the O_3 observation being evaluated. For example, if the daily maximum O_3 occurs at 4 p.m. and the straightline distance is 50 miles, the mean average resultant wind velocity is 50 miles/8 hours = 6.25 mph.

It now remains to combine information regarding emissions likely to importantly influence observed O_3 with calculated back trajectories. This is done by identifying that portion of the trajectory corresponding to 0800-1200 LDT, as shown in Figure 5.

3.6 Evaluation of the Methodology to Identify Overwhelming Transport

The procedure for identifying overwhelming transport, described in Sections 3.3 - 3.5, has been evaluated examining incidents of O_3 > 0.12 ppm near Hartford, Connecticut, during June-August 1983. Six ozone sites were judged to be located such that it may be sufficiently ambiguous whether a high incident is due to local Connecticut (Hartford) emissions or due to overwhelming transport from more remote sources. These six sites are shown in Figure 6. In all there are 21 days during June-August 1983 on which one or more of these sites observed O_3 > 0.12 ppm. Figure 7 includes additional key O_3 sites in Connecticut and Massachusetts. By examining the timing and sequence of high O_3 at the sites in

CALCULATIONS FOR FIRST TWO PERIODS OF EXAMPLE 1

Period	Adjusted Wind Speed	Direction	Northerly Component (Eq. (2b))	Easterly Component (Eq. (2a))	Ri, mi	$1/R_i^2$
0	6	260	- 1.04	- 5.91	10	.0100
	4.5	240	- 2.25	- 3.90	30	.0011
	7.5	180	- 7.50	0	50	.0004
Σ	--	---	-10.79	- 9.81		.0114

Eq. (3)

$$\bar{V}_o = \left| \left(\left(\frac{1}{.0114} \right)[.01)(-5.91)+(.0011)(-3.90)+(.0004)(0)] \right)^2 + \left(\left(\frac{1}{.0114} \right)[(.01)(-1.04)+(.0011)(-2.25)+(.004)(-7.50)] \right)^2 \right|$$

$$\bar{V}_o = 5.7 \text{ mph}$$

Eq. (4)

$$\bar{\phi}_o = \cos^{-1} \left[\frac{\left(\frac{1}{.0114} \right)[(.01)(-1.04)+(.0011)(-2.25)+(.0004)(-7.50)]}{5.7} \right] = 104° \text{ or } 256°$$

Since $\Sigma (\text{easterly component})_i = -9.81 < 0$, $\bar{\phi}_o = \underline{256°}$

Eq. (5)

$$2\theta = \cos^{-1} \left[\frac{5.7}{(1/.0114)[(.01)(6)+(.0011)(4.5)+(.0004)(7.5)]} \right] = 17°$$

$$\therefore \quad \theta = 8.5°$$

EXAMPLE CALCULATIONS (CONTINUED)

Period	Adjusted Wind Speed	Direction	Northerly Component (Eq. (2b))	Easterly Component (Eq. (2a))	Ri, mi	$1/R_i^2$
1	7.5	250	- 2.57	- 7.05	14	.0051
	9	230	- 5.79	- 6.90	26	.0015
	9	190	- 8.87	- 1.56	47	.0005
				-15.51		.0071

Eq. (3)

$$\bar{V} = \left(\left(\frac{1}{.0071}\right)[(.0051)(-7.05)+(.0015)(-6.90)+(.0005)(-1.56)]\right)^2 + \left(\left(\frac{1}{.0071}\right)[(.0051)(-2.57)+(.0015)(-6.90)+(.0005)(-1.56)]\right)^2$$

$\bar{V}_1 = 7.4$ mph

Eq. (4)

$$\bar{\phi}_o = \cos^{-1}\left[\frac{\frac{1}{.0071}[(.0051)(-7.05)+(.0015)(-6.90)+(.0005)(-1.56)]}{7.4}\right] = 154° \text{ or } 206°$$

Since Σ (easterly component)$_i$ = -15.51 < 0, $\bar{\phi}i$ = 206°

Eq. (5)

$$2\theta = \cos^{-1}\left[\frac{\frac{1}{.0071}[(.0051)(7.5)+(.0015)(9)+(.0005)(9)]}{7.4}\right] = 22°$$

$\therefore\ \theta = 11°$

Similar calculations are performed in periods 2-7.

Figure 7 during the 21 incidents of high O_3 near Hartford, preliminary judgments were made about whether an incident is primarily attributable to overwhelming transport from the New York CMSA or is importantly influenced by more local emissions. Table II presents timing of high O_3 for days on which high O_3 was observed at the six sites shown in Figure 6. Under each day, all sites with O_3 > 0.12 are listed in order, from SW to NE. Sites observing daily maximum $O_3 \geq$ 0.18 ppm are asterisked. Data summarized in Table II were examined to make a preliminary judgment about likely importance of overwhelming transport vs. local influences. Days were classified in one of three categories:

I -overwhelming transport is the most important cause of an exceedance

II -overwhelming transport is likely, but so are locally-induced secondary peaks, or too uncertain to make a preliminary call based on air quality data alone

III -local emissions likely influence observed exceedances (overwhelming transport unlikely).

Results are presented in Table III.

Methodology described in Sections 3.3 and 3.4 was next applied to see whether conclusions drawn from the trajectory analyses are consistent with those reached independently from the review of air quality data.

Two days identified in each class were selected for analysis. These were 6/30, 6/15, 8/26, 8/8, 7/29, and 6/27. For each day, two to three monitoring sites were selected. This resulted in a total of 16 cases for review. Meteorological data for these days were run in the TRAJECTORY model. Results of these modeling runs are shown in Table IV. Graphical displays of the results for several days are shown in Appendix A.

In many cases, preliminary classifications based upon air quality data alone do not agree with classifications based upon results of the TRAJECTORY

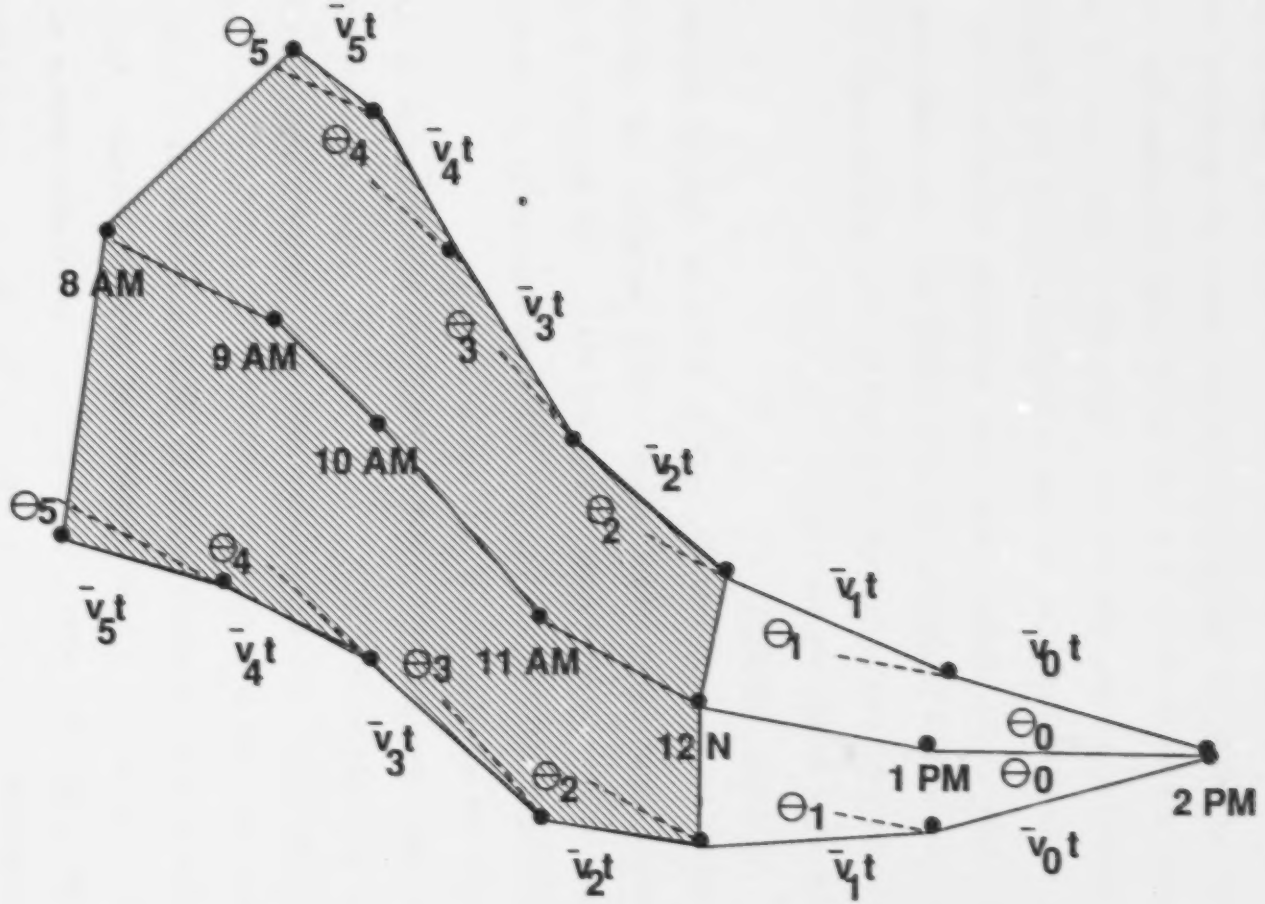


Figure 5 - Multiperiod Back Trajectory With Area Most Likely Contributing to Observed Ozone Identified

model. This may indicate that preliminary indications may not be sufficient to accurately relate emissions to an ozone exceedance at a downwind monitor.

Times of observed and modeled ozone peaks at monitors along the trajectories are shown in Table V. Of the 16 cases for comparison, the exact time is predicted 6 times (38 percent), while for 4 other cases (25 percent), the time of the modeled ozone maximum is within 1 hour of the observed peak. For most cases, it appears that the predicted trajectory is a fair approximation of the trajectory actually travelled. The lone exception is 8/8, where observed peaks occurred much earlier than modeled peaks indicating the modeled wind speeds are too low.

3.7 Multi-day Transport

It should be apparent that the methods discussed thus far address single day transport from large urban plumes which overwhelm any contributions attributable to more local (usually smaller) MSA's. The analysis is confined to single day situations due to (a) unrepresentativeness of surface data during nighttime and (b) lack of data collected aloft.

Multi-day transport is considered through specification of boundary conditions to urban scale models. As a result of longer residence times and overnight wind shear, individual plumes more than 1 day old are expected to be less identifiable and more diffuse. Therefore, boundary conditions specified for use with urban scale models should be representative of large areas (e.g., $\geq$ 18 km x 18 km). Without benefit of Regional Oxidant Model (ROM) applications (Lamb, 1983, 1984), it is difficult to estimate whether multi-day transport can lead to overwhelming transport into moderate size cities. Ozone $\geq$ 0.12 ppm during the early morning (e.g., before 10 a.m. LDT) may well reflect such transport. However, it may also reflect recirculation from the

Figure 6 - Ozone Monitoring Sites Near Hartford, CT.

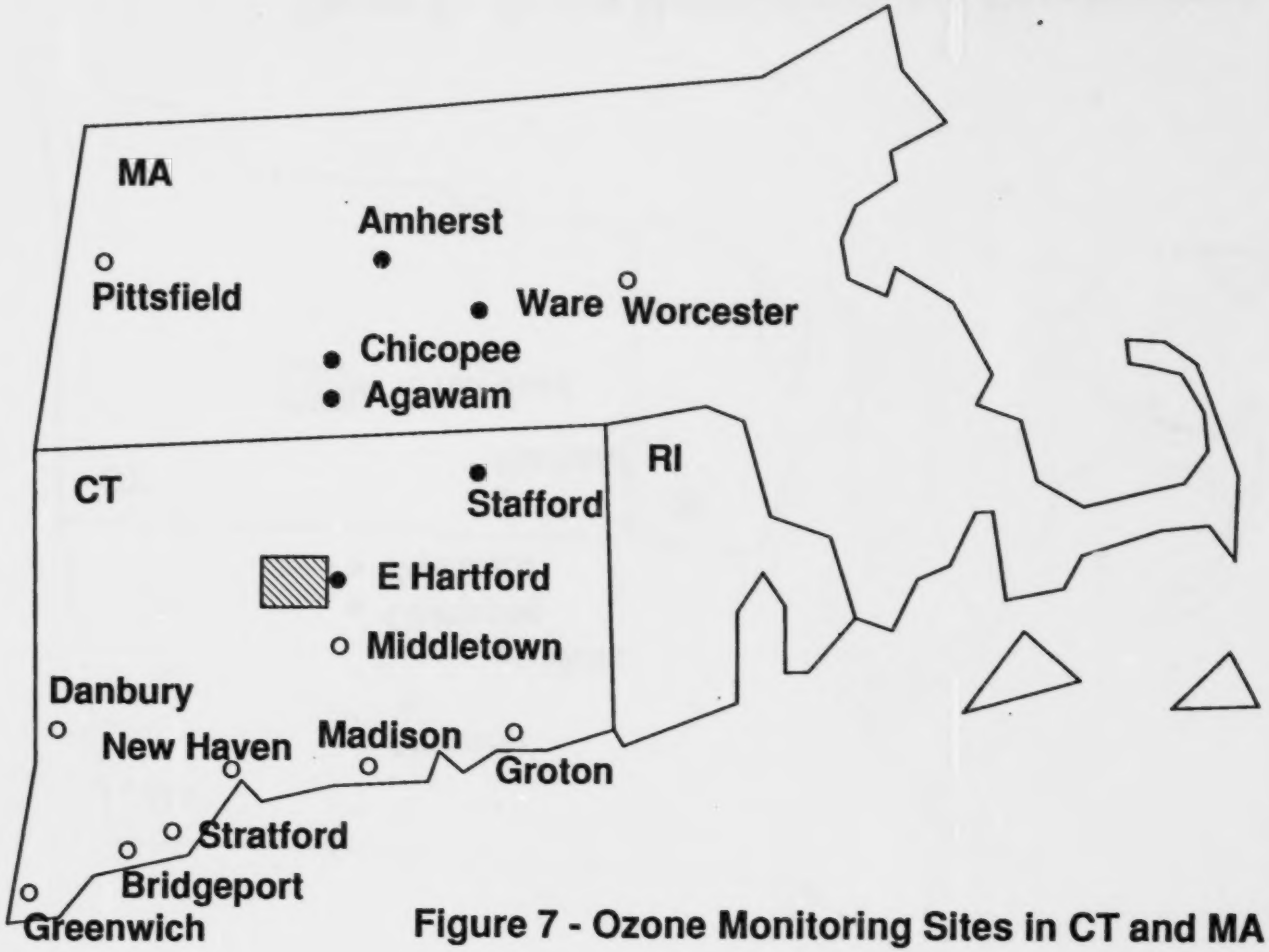


Figure 7 - Ozone Monitoring Sites in CT and MA Used to Assess Overwhelming Transport

TABLE II. DAYS, TIMES OF OZONE > 0.12 PPM

June 4	June 5	June 6	June 7
Chicopee (12-3)	Stratford (3) Chicopee (11-2)	Chicopee (12)	Chicopee (3)
June 14	**June 15**	**June 17**	**June 27**
Danbury (10-6)* Stratford (5-6) New Haven (12-6) Middletown (12, 3-8) E. Hartford (12-2) Stafford (12-4)	Greenwich (11-4)* Danbury (10-6) Bridgeport (11-4)* Stratford (11-5)* Madison (11-4)* Middletown (10-3)* E. Hartford (11-2)* Stafford (10-1) Groton (12-3) Ware (2-3) Worcester (12-1)	Stafford (1-3) Amherst (2-5) Ware (3-4)	Greenwich (12-4) Danbury (11-4) Bridgeport (12-4)* Stratford (11-5)* New Haven (11-4)* Madison (12-4)* Middletown (11-3) Stafford (11) Groton (11-3)* Agawam (2-3)
June 30	**July 2**	**July 3**	**July 4**
Greenwich (12-1) Stratford (12-3) New Haven (12-4) Madison (12-3) Middletown (4) E. Hartford (4-5) Stafford (3-6) Groton (12-3)* Agawam (4-6) Amherst (6) Ware (5-7)	Bridgeport (11-3) Stratford (12-3)* New Haven (12-4)* Madison (1-3) Middletown (12-4)* Stafford (6)	Stratford (5-6) New Haven (3-5) Groton (1-7) Agawam (2-6)	Greenwich (10-11) Danbury (9-4)* Bridgeport (10-2) Stratford (2) New Haven (10-3)* Middletown (11-4) E. Hartford (1-4) Stafford (3-4) Groton (9-6) Agawam (10-8)* Chicopee (10-7)* Amherst (11-7)

TABLE II (CONTINUED)

July 12	July 28	July 29	July 31
Greenwich (11-5)*	Danbury (12-4)*	Danbury (1-3)	Danbury (3-5)
Bridgeport (3-5)	Agawam (12-6)	Middletown (1)	Agawam (2-7)
Stratford (12-5)	Chicopee (12-4)	E. Hartford (2)	
New Haven (1, 5)	Amherst (12-5)	Stafford (1-4)	
Madison (1-6)	Pittsfield (6 pm-9 pm)*	Agawam (2-5)*	
E. Hartford (1)		Chicopee (4-5)	
Stafford (8 pm-10 pm)		Amherst (3-6)	
Groton (midnight, 12-8)*		Ware (2-3)	
Agawam (1-6)			

August 8	August 16	August 17	August 22
Greenwich (2-3)	Greenwich (11-3)	Greenwich (11-4)	Stratford (1)
Bridgeport (1)	Danbury (4-5)	Danbury (12-6)	E. Hartford (3)
Stratford (11-4)*	Stratford (11-3)	Bridgeport (12-3)	Stafford (3)
New Haven (12-4)*	New Haven (11-12)	Stratford (11-5)*	Chicopee (5)
Madison (1)	Madison (12-2)	New Haven (12-4)*	
Middletown (2-5)	Middletown (4-5)	Madison (1-3)	
E. Hartford (6)	E. Hartford (5)	Middletown (12-5)*	
Stafford (6)	Groton (2)	E. Hartford (2-6)*	
Groton (1)		Stafford (1, 4-7)	
Agawam (4-8)		Groton (11-7)	
		Agawam (6 pm-8 pm)	
		Chicopee (5 pm-8 pm)	
		Amherst (8 pm-9 pm)	

August 26	August 27
Danbury (1-4)	Greenwich (12-4)
E. Hartford (2-4)	Danbury (4-7)*
Stafford (12-5)*	Bridgeport (12-4)
Agawam (4-5)	Stratford (12-4)
Chicopee (4-6)	New Haven (12-5)
Amherst (1, 5-6)	E. Hartford (5-7)
	Groton (12-4)*

*Sites observing $O_3 \geq 0.18$ ppm

TABLE III. CLASSIFICATIONS BASED ON REVIEW OF AIR QUALITY DATA ALONE

I	II	III
Days with likely overwhelming transport	Days with both transport and local influences, or uncertain	Days where overwhelming transport is unlikely
6/30	6/15	6/4
8/8	6/27	6/5
8/16	7/2	6/6
8/17	7/3	6/7
8/27	7/4	6/14
	7/12	6/17
		7/28
		7/29
		7/31
		8/22
		8/26

TABLE IV. COMPARISON OF CLASSIFICATION BASED UPON TRAJECTORY MODEL AND AIR QUALITY DATA ALONE

MONITOR	DATE	CLASSIFICATION	
		TRAJECTORY MODEL	AIR QUALITY DATA
Amherst	6/30	I	I
Agawam	6/30	I	I
E. Hartford	6/30	I	I
Ware	6/15	II	II
E. Hartford	6/15	II	II
Amherst	8/26 (6-7 pm)	I	III
Amherst	8/26 (1-2 pm)	III	III
Chicopee	8/26	I	III
Stafford	8/26	I	III
Agawam	8/8	I	I
E. Hartford	8/8	I	I
Agawam	7/29	I	III
Chicopee	7/29	I	III
Stafford	7/29	I	III
Agawam	6/27	II	II
Stafford	6/27	III	II

TABLE V. COMPARISON OF OBSERVED AND PREDICTED TIMES OF MAXIMUM OZONE

Date	Starting Location	Monitor	Predicted Time of Max. Ozone	Observed Time of Max. Ozone
6/30	Amherst	Chicopee	6	5-6
		Bridgeport	1	2-3
		New Haven	1	3-4
6/30	E. Hartford	New Haven	3	3-4
6/30	Agawam	Bridgeport	2	2-3
8/26	Amherst	Danbury	2	2-3
8/26	Chicopee	Agawam	5	5-6
		Danbury	2	3-4
8/26	Stafford	E. Hartford	4	3-4
		Bridgeport	1	1-2
8/8	Agawam	Bridgeport	4	1-2
		New Haven	5	3-4
8/8	E. Hartford	Bridgeport	4	1-2
7/29	Agawam	Bridgeport	2	12-1
		Greenwich	1	1-2
7/29	Stafford	E. Hartford	2	2-3

CMSA/MSA under review. Incidents of early morning O_3 NAAQS exceedances need to be examined on a case-by-case basis to see which of these two possibilities is most likely. If recirculation is judged the more likely cause of the incident, it will probably have to be treated as an "irreducible exceedance" (see Section 2.1) unless a more sophisticated modeling approach like the Urban Airshed Model (UAM) is used.

Incidents of $O_3 > 0.12$ ppm in the early morning are likely to be relatively rare. The more typical case is one where moderate O_3 and precursor concentrations, representing a mix of multi- and single-day transport, are advected into an MSA. Section 4.0 outlines appropriate assumptions regarding boundary conditions in the absence of a ROM analysis.

4.0 CONSIDERING TRANSPORT DURING INCIDENTS WHERE LOCAL EMISSIONS ARE SIGNIFICANT CONTRIBUTORS TO OZONE

In this section, we consider incidents of high O_3 in which local emissions play a significant role, but in which transport is still a factor. For such incidents, urban scale models (like UAM or city-specific EKMA) are used to evaluate whether locally prescribed controls are sufficient to reduce $O_3 \leq 0.12$ ppm on modeled days. Difficulty in reaching this goal is affected by: (a) present levels of ozone and its precursors transported from upwind sources and (b) assumptions made about how concentrations of presently transported pollutants may change between the base and projected periods. Urban scale models treat the following transported species of pollutants as boundary conditions.

(a) Ozone

(b) NMOC (and its composition)

(c) NO_x (and its composition)

(d) CO

Each of these is considered separately in the following subsections. During certain times of day (early morning, night), surface measurements may not be representative of pollutants transported into an MSA. Therefore, it is sometimes necessary to provide concentration estimates for two or more vertical layers.

4.1 Ozone

4.1.1 Present Conditions (Base Case)

Use of surface O_3 measurements is recommended as the most feasible means for estimating transported O_3 during particular incidents of interest for modeling.

The guidance in USEPA (1989a) recommends assuming transported O_3 in the surface layer to be 0 ppm. This assumption is justified because the modeled trajectory begins in the center of a city where aged, transported O_3 is presumed to have been removed by surface deposition or scavenged by NO_x. A constant value for O_3 aloft equal to that seen at a representative upwind monitor(s) during the hour following breakup of the nocturnal inversion is recommended. If time of the inversion breakup is not known, use the 10-12 LDT average (i.e., average of 10 a.m. and 11 a.m. readings). Use of a constant O_3 value aloft is justified by the presumption that further O_3 formation in a layer trapped aloft, away from fresh sources of precursors, will be limited by lack of NO_x, reactive NMOC, or both.

4.1.2 Projected (Future) Conditions

In the absence of a regional scale analysis, Figure 8 should be used to estimate future transport, as described in USEPA (1989a). Curves in Figure 8

were derived using changes in typically observed O_3 levels predicted as likely with OZIPM4/EKMA (USEPA, 1989a) at the end of 1 day's irradiation under various assumed sets of meteorological conditions and moderate (~ 20 percent) VOC emission reductions.

4.2 Nonmethane Organic Compounds

4.2.1 Present NMOC

It is important to emphasize that NMOC data collected to derive NMOC/NO_x ratios for use in EKMA should not be used to estimate boundary conditions. These measurements are typically made in center cities. Therefore, they are not likely to represent NMOC values averaged over large distances in relatively rural areas.

If rural upwind NMOC data are not available, a diurnally constant default value suggested in USEPA (1989a) is recommended.

Use of constant default NMOC concentrations and speciations are recommended for the layer aloft (USEPA, 1989a). These are presented in Table VI. These values are derived from early morning (~ 6-9 a.m.) measurements conducted upwind from several cities using aircraft (USEPA, 1987c). For the reasons described in USEPA (1989a), NMOC in the surface layer may be assumed to be 0 in an EKMA analysis.

4.2.2 Future Transported NMOC

In the absence of regional scale modeling information, it is recommended ıt future transported NMOC be reduced 20 percent in all vertical layers. ɔosition should remain constant. These assumptions are consistent with ɜ used to derive future transported O_3 estimates in Figure 8.

4.3 Oxides of Nitrogen

4.3.1 Present Transported NO_x

If EKMA is used, surface transport of NO_x can be ignored. Constant default assumptions recommended in USEPA (1989a) should be used (i.e., 2 ppb NO_x) for NO_x aloft. It can be assumed that this NO_x is all present as NO_2.

4.3.2 Future Transported NO_x

In the absence of any rationale to the contrary, it is recommended that transported NO_x levels and composition be assumed constant.

4.4 Carbon Monoxide

Large changes in relatively high urban concentrations of CO may affect sensitivity of O_3 to changes in VOC and NO_x emissions. However, background levels of CO are low and may not be subject to dramatic changes. Therefore, even though EKMA can consider transported CO, this factor can most likely be ignored without affecting estimated O_3 values.

FIGURE 8

FUTURE OZONE TRANSPORT AS A FUNCTION OF PRESENT TRANSPORT

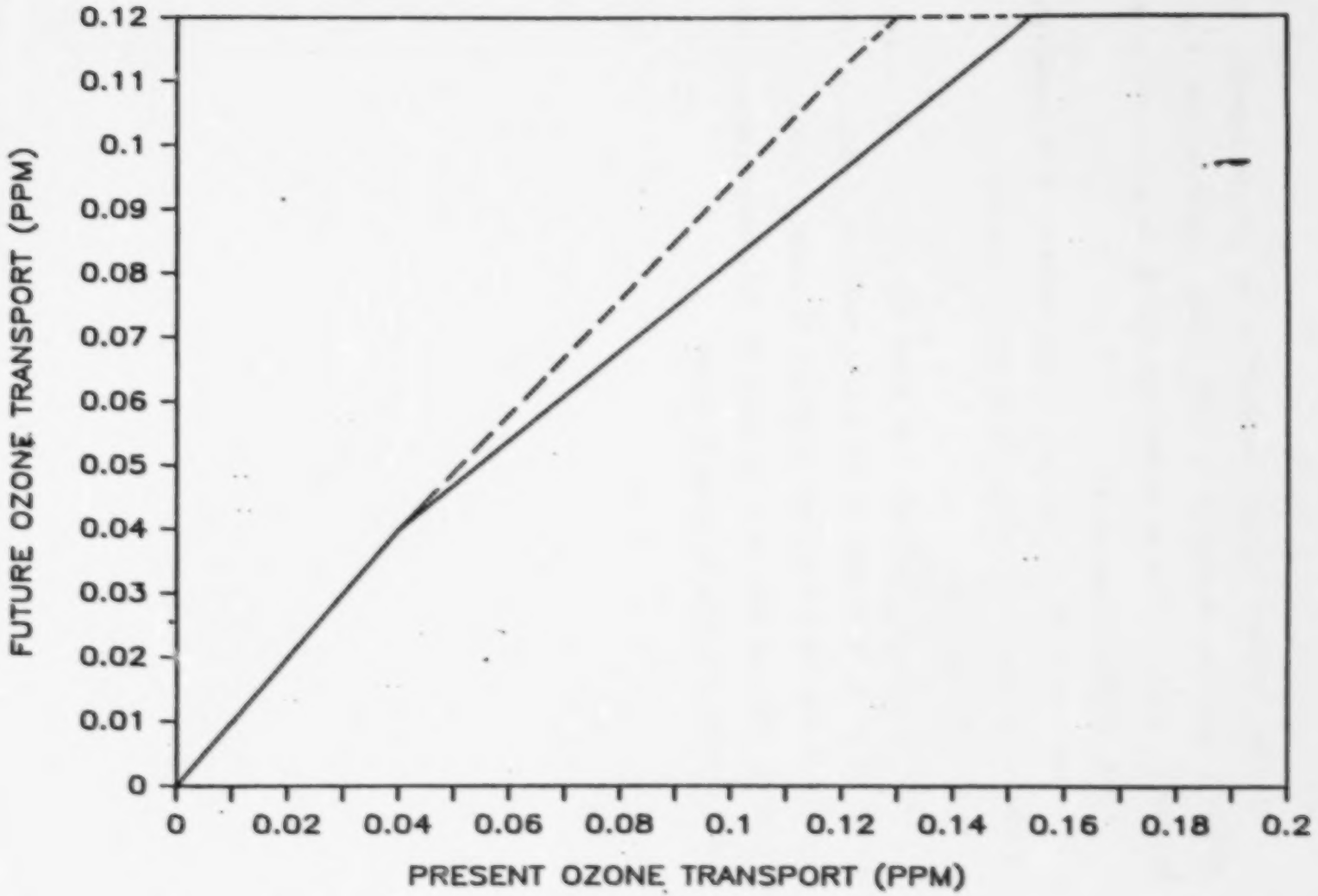


TABLE VI. RECOMMENDED DEFAULT VALUES FOR EKMA

Total NMOC aloft		30 ppbC
NO_x aloft		2 ppb
Speciation of NMOC aloft		
	OLE	.020
	PAR	.498
	TOL	.042
	XYL	.026
	FORM	.070
	ALD2	.037
	ETH	.034
	UNR	.273

Source: USEPA, 1989a

5.0 REFERENCES CITED

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6.0 ACKNOWLEDGMENTS

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APPENDIX A

USER'S MANUAL FOR THE TRAJECTORY MODEL

PURPOSE

The TRAJECTORY model is intended for the purpose of identifying areas with emissions of ozone precursors that are likely to contribute to ozone exceedances on a specific day. This is accomplished by using surface wind speeds and directions from several nearby meteorological stations. A back trajectory is then defined from the time of the ozone exceedance to the 8-12 a.m. LDT period. Due to the uncertainty that surface winds are representative of meteorological conditions aloft during the nighttime, this model is only to be applied for ozone exceedances occurring no later than 8-9 p.m. LDT. The TRAJECTORY model cannot, therefore, address transport that occurs overnight. For a more detailed discussion of how to consider transport in ozone State Implementation Plans, see earlier sections of this document. The remainder of this section outlines how to apply the TRAJECTORY model.

DESCRIPTION OF MODEL AND INPUTS

The TRAJECTORY model is a spreadsheet which consists of three sections: an input section, a results section, and a calculation section. The user should only be concerned with the first two sections.

The input section requires three sets of input from the user: UTM coordinates for the monitor which has the observed ozone exceedance, UTM coordinates for the meteorological stations, and wind speed and directions for each hour from 8 a.m. LDT to the time of the ozone exceedance for from 3-10 meteorological stations. In addition there are locations to enter the monitor name or number and the date for the simulation. An accompanying program, called UTM, which is on the disk with the TRAJECTORY model can be used to determine UTM coordinates given latitude and longitude. It can also be used

to "force" all UTM coordinates to be in the same UTM ozone. This is necessary before running the TRAJECTORY model.

The wind speed data must be in knots. The user can convert other units to knots by using the following conversion factors (m/sec x 1.9425 = knots; mi/hr x 0.86839 = knots; km/hr x 0.53959 = knots). This can easily be done by creating an input spreadsheet and converting units prior to entering the data into the TRAJECTORY model. Wind directions represent the direction from which the wind is blowing. For example, a wind blowing from the south (to the north) is 180°.

UTM coordinates should only be included for meteorological stations that are to be utilized in the particular day and/or monitor under review. Including coordinates for meteorological stations and then not providing hourly meteorological data for that station can lead to erroneous results.

RUNNING THE MODEL

The description of the operation of this program will assume that the user is working with LOTUS 123. Many other spreadsheet programs can also be used to run the TRAJECTORY model, but the commands may differ from those listed here. The user should consult the spreadsheet manual he or she is working with to determine equivalent commands to those shown.

LOTUS 123 should be started up and the TRAJECTORY model loaded using the File Retrieve (/FR) command. If you are running TRAJECTORY from a diskette, you must first use the File Directory (/FD) command to instruct LOTUS where to find the files. The file to be retrieved is TRAJECT2.WK1.

Data can be entered into the spreadsheet in two ways: either manually or by building spreadsheets with input data and then using the File Combine

Copy (/FCC) command to incorporate these spreadsheets into the TRAJECTORY spreadsheet. Both methods will be described and an example using the File Combine Copy command will be outlined.

Figure A-1 shows what the input section of the TRAJECTORY Model looks like. The areas that require the user to input data are highlighted with boxes. Each area will be described.

The UTM coordinates for the ozone monitor with the observed ozone exceedance are entered into cells E3 and F3. Cell E3 the UTM E (East) coordinate while cell F3 contains the UTM N (North) coordinate.

A name or ID number for the ozone site is entered in cell I3. The date of the exceedance is entered into cell I5.

The UTM coordinates for the meteorological stations are entered into cells C9 through D-18. Cells C9 through C18 contain the UTM E coordinates, while cells D9 through D18 contain the UTM N coordinates.

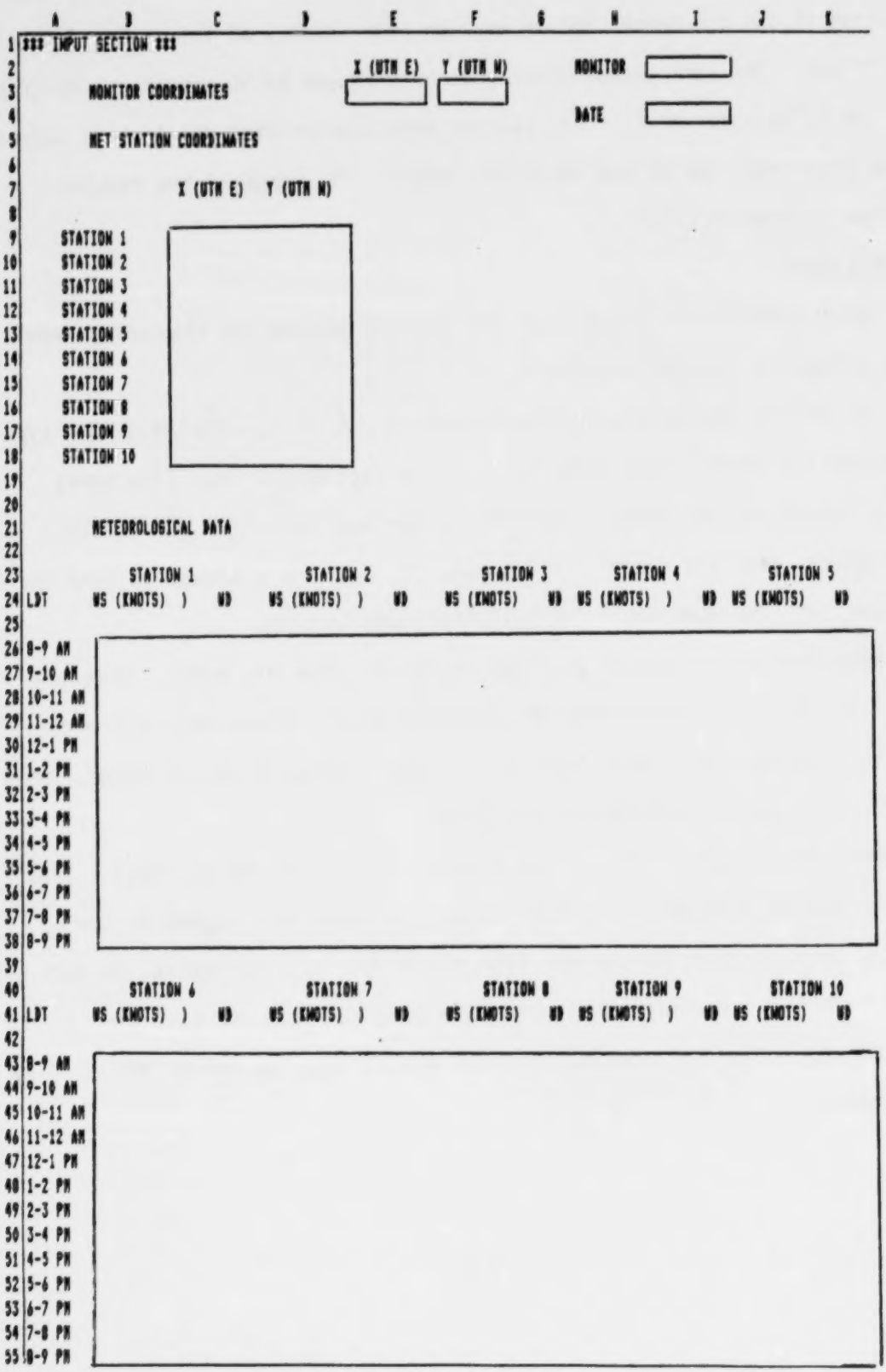
The meteorological data are entered into two areas: cells B26 and K38 and B43-K55. Cells B26-B38 contain the wind speeds for station 1, while cells C26-C38 contain the wind directions for station 1. The data for station 2 are entered into cells D26-D38 and E26-E38. Data for the sixth station is entered into cell B43-B55 and C43-C55.

To manually enter data the user must move the cursor to the appropriate cell, type in the value and then press the enter key. The example shown below will describe how to use the File Combine Copy command to enter data.

After all data has been entered the user must push the F9 key. This instructs the program to carry out all calculations and should only take a few seconds.

FIGURE A-1

INPUT SECTION OF THE TRAJECTORY MODEL



The results section contains two sets of information: an hour-by-hour position of the air parcel and an hour-by-hour summary of the meteorological conditions. The wind speeds shown have been raised by 50 percent as described earlier in this document. This section should be printed out in hard copy and saved after each run of the TRAJECTORY model. The range of the results section is from A7..J102.

EXAMPLE RUN

This example will assume that the user is running the TRAJECTORY model from a diskette located in Drive A.

To set the appropriate directory type in /FD (file directory) then type in A: and hit enter. Next type in /FR (file retrieve). Four file names should appear on the screen. Move the cursor over such that TRAJECT2.WK1 is highlighted, then hit enter. It may take 30 second to a minute to load the program. Hit the HOME key to move to the input section.

Move the cursor to cell E3, type in 704.31, then hit enter. Move the cursor to cell F3, type in 4696.06, then hit enter. These are the coordinates for the ozone monitor. Move to cell I3, type in Amherst and hit enter. Move to cell I5, type in '8/26/83 and hit enter.

Move the cursor to cell C9 and type in /FCC (file combine copy). Type in E for entire file and hit enter. Four file names will appear on the screen. In this case the correct file, COORD.WK1, is highlighted, so just hit enter. The UTM coordinates for nine meteorological stations have been stored in COORD.WK1. The /FCC command copies this data into the TRAJECTORY spreadsheet.

Move the cursor to cell B26. Type in /FCC and hit enter. Enter N for named range. The computer will ask for a range name. Type in PART1 and hit enter. The computer will then display four file names. Move the cursor over and highlight M82683.WK1, then push enter, windspeed and direction data for the first five meteorological stations have been entered.

Move the cursor to cell B43. Type in /FCC and hit enter. Enter N for named range. Type in PART2 and hit enter. Move the cursor to highlight M82683.WK1 and then push enter. Data for the last four meteorological stations has now been entered. (The user is encouraged to review the manual for his or her particular spreadsheet program to determine how to set up these input spreadsheets).

The final step is to push F9. It should only take a few seconds to make all the necessary calculations.

Move to the results section (A57-J102) and review the results. Table A-1 contains the results from the example run which should be compared with the user's results.

The final step is for the user to manually plot the coordinates in the results section to determine the source area. This may be done manually or by using other commercially available software programs. Two approaches may be taken. The user might only plot coordinates for 8 a.m. - noon to define the source area. However, it is often desirable to plot the entire trajectory so that the location of the parcel at specific times can be compared to ozone peaks at monitors passed over during the day. Figure A-2 displays the trajectory for this day and monitor. Other examples are also shown. It should be noted that all examples shown are exactly that; only examples. They

not be considered final TRAJECTORY analyses for the monitors and days illustrated.

TABLE A-1

OUTPUT FOR EXAMPLE RUN

RESULTS SECTION ### ANNEXST 8/26/83

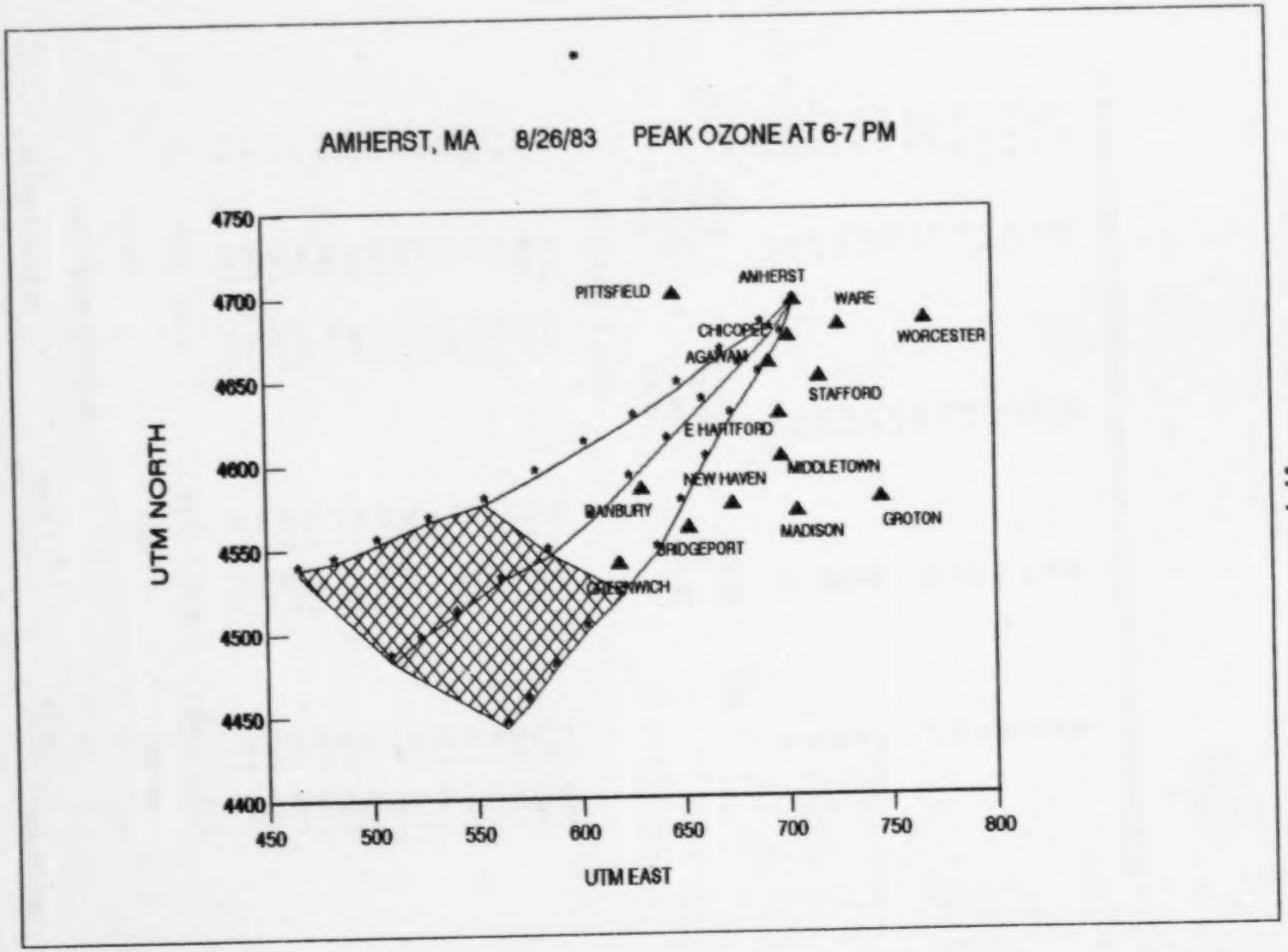
HOURLY LOCATION OF AIR PARCEL

LST	LEFT EDGE X (UTM E)	LEFT EDGE Y(UTM N)	CENTER X (UTM E)	CENTER Y (UTM N)	RIGHT EDGE X (UTM E)	RIGHT EDGE Y(UTM N)
9 PM	704.3	4696.1	704.3	4696.1	704.3	4696.1
8 PM	704.3	4696.1	704.3	4696.1	704.3	4696.1
7 PM	704.3	4696.1	704.3	4696.1	704.3	4696.1
6 PM	688.6	4681.8	692.7	4678.3	697.7	4675.9
5 PM	668.6	4665.0	677.0	4657.4	687.0	4652.1
4 PM	648.2	4646.1	659.7	4635.7	673.2	4628.0
3 PM	626.8	4627.2	642.6	4612.8	661.2	4602.0
2 PM	602.5	4611.3	623.8	4590.7	649.3	4575.6
1 PM	578.7	4594.0	605.1	4567.9	637.0	4548.8
NOON	554.5	4578.1	584.8	4547.3	621.4	4524.4
11 AM	527.7	4567.3	561.5	4530.2	603.2	4502.0
10 AM	502.7	4554.5	540.5	4511.6	587.3	4478.8
9 AM	482.2	4543.5	523.4	4495.7	575.0	4459.1
8 AM	465.0	4538.2	508.8	4485.3	564.3	4444.6

HOURLY SUMMARY OF METEOROLOGY

LST	AVERAGE WIND SPEED (KILOMETERS PER HOUR)	RESULTANT WIND SPEED (KILOMETERS PER HOUR)	RESULTANT WIND DIRECTION	THETA
8-9 PM	0.0	0.0	0	0
7-8 PM	0.0	0.0	0	0
6-7 PM	22.0	21.2	213	15
5-6 PM	26.7	26.1	217	13
4-5 PM	28.1	27.8	219	9
3-4 PM	29.2	28.6	217	12
2-3 PM	30.2	29.0	220	16
1-2 PM	30.5	29.5	219	15
12-1 PM	29.6	29.0	225	12
11-12 AM	29.8	28.9	234	14
10-11 AM	28.9	28.1	229	14
9-10 AM	24.1	23.3	227	15
8-9 AM	18.9	18.0	235	18

FIGURE A-2


AMHERST, MA 8/26/83 PEAK OZONE AT 6-7 PM
UTM NORTH
4750
4700
4650
4600
4550
4500
4450
4400
UTM EAST
450
500
550
600
650
700
750
800
PITTSFIELD
AMHERST
WARE
WORCESTER
CHICOPEE
AGAWAM
STAFFORD
E HARTFORD
MIDDLETOWN
NEW HAVEN
DANBURY
GROTON
MADISON
BRIDGEPORT
GREENWICH

ADDITIONAL EXAMPLE RUNS

TABLE A-3

RESULTS SECTION ### AMHERST 6/30/83

HOURLY LOCATION OF AIR PARCEL

LST	LEFT EDGE X (UTM E)	LEFT EDGE Y(UTM M)	CENTER X (UTM E)	CENTER Y (UTM M)	RIGHT EDGE X (UTM E)	RIGHT EDGE Y(UTM M)
9 PM	704.3	4696.1	704.3	4696.1	704.3	4696.1
8 PM	704.3	4696.1	704.3	4696.1	704.3	4696.1
7 PM	704.3	4696.1	704.3	4696.1	704.3	4696.1
6 PM	692.0	4672.9	698.0	4670.7	704.3	4669.9
5 PM	672.5	4650.4	685.5	4643.6	699.9	4640.4
4 PM	653.6	4623.2	669.2	4614.8	686.2	4610.3
3 PM	636.6	4604.3	660.9	4590.7	688.0	4584.8
2 PM	626.8	4584.0	659.6	4568.2	695.4	4563.6
1 PM	618.9	4564.6	659.3	4547.3	702.8	4544.0
NOON	608.6	4552.3	657.5	4531.4	710.0	4529.7
11 AM	598.5	4548.8	651.9	4522.2	711.6	4519.1
10 AM	590.5	4549.0	645.6	4517.3	709.8	4511.3
9 AM	581.7	4551.0	636.9	4514.8	703.4	4504.8
8 AM	569.7	4555.3	624.3	4516.5	698.7	4504.0

HOURLY SUMMARY OF METEOROLOGY

LST	AVERAGE WIND SPEED (KILOMETERS PER HOUR)	RESULTANT WIND SPEED (KILOMETERS PER HOUR)	RESULTANT WIND DIRECTION	THETA
8-9 PM	0.0	0.0	0	0
7-8 PM	0.0	0.0	0	0
6-7 PM	27.0	26.2	194	14
5-6 PM	31.0	29.8	205	16
4-5 PM	33.3	33.1	210	9
3-4 PM	27.7	25.5	199	23
2-3 PM	24.4	22.5	183	23
1-2 PM	22.5	20.9	181	22
12-1 PM	19.1	16.0	187	33
11-12 AM	14.0	10.8	211	40
10-11 AM	10.2	8.0	233	39
9-10 AM	10.5	9.1	254	29
8-9 AM	13.0	12.7	278	12

FIGURE A-3

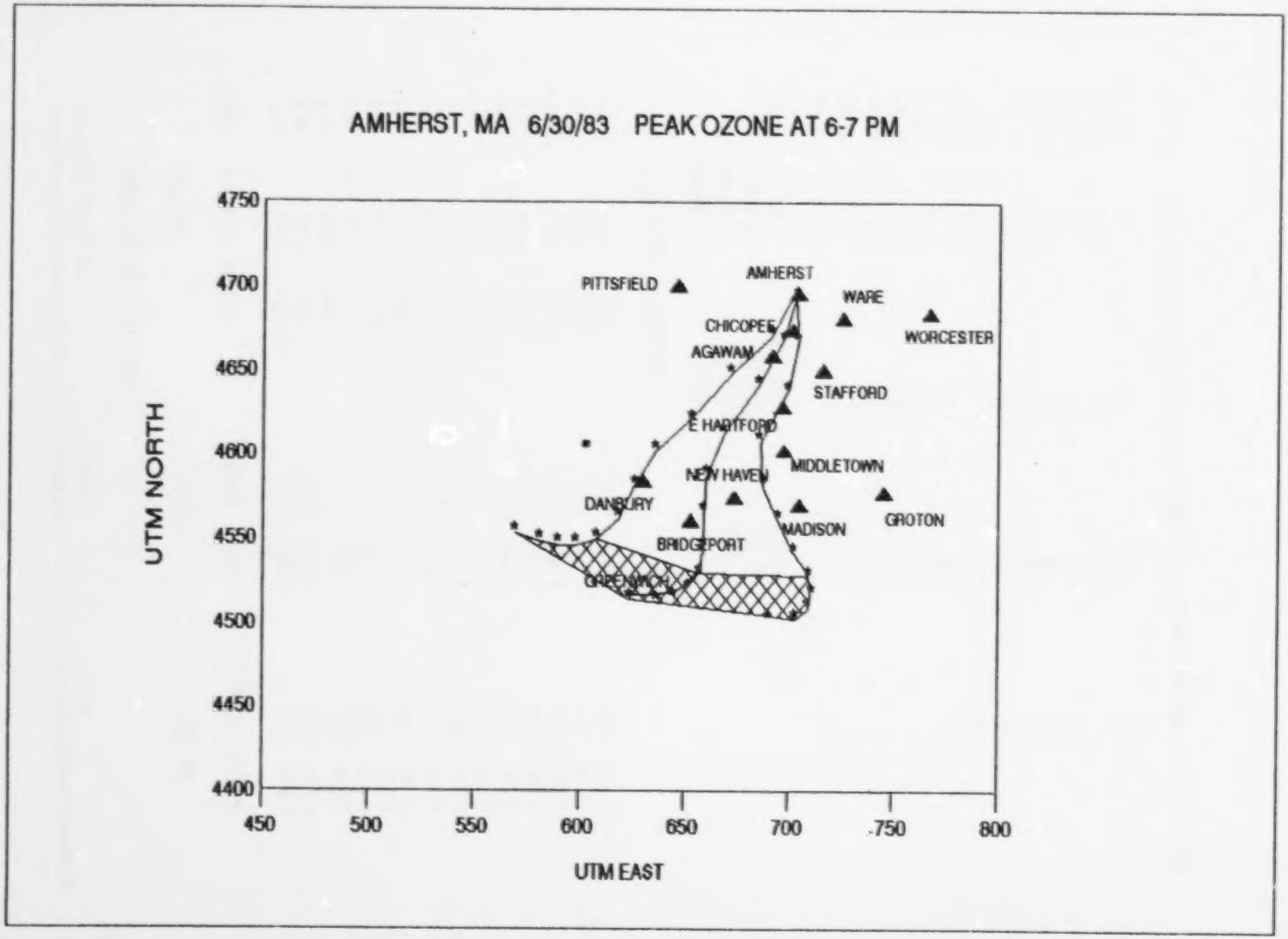

AMHERST, MA 6/30/83 PEAK OZONE AT 6-7 PM
UTM NORTH
4750
4700
4650
4600
4550
4500
4450
4400
450
500
550
600
650
700
750
800
UTM EAST
PITTSFIELD
AMHERST
WARE
WORCESTER
CHICOPEE
AGAWAM
STAFFORD
E HARTFORD
MIDDLETOWN
NEW HAVEN
DANBURY
MADISON
GROTON
BRIDGEPORT
GREENWICH

TABLE A-4

RESULTS SECTION E HARTFORD 6/30/83

HOURLY LOCATION OF AIR PARCEL

LDT	LEFT EDGE X (UTM E)	LEFT EDGE Y(UTM M)	CENTER X (UTM E)	CENTER Y (UTM M)	RIGHT EDGE X (UTM E)	RIGHT EDGE Y(UTM M)
9 PM	696.9	4628.5	696.9	4628.5	696.9	4628.5
8 PM	696.9	4628.5	696.9	4628.5	696.9	4628.5
7 PM	696.9	4628.5	696.9	4628.5	696.9	4628.5
6 PM	696.9	4628.5	696.9	4628.5	696.9	4628.5
5 PM	696.9	4628.5	696.9	4628.5	696.9	4628.5
4 PM	676.2	4604.1	682.3	4600.1	689.1	4597.5
3 PM	659.9	4585.0	675.8	4575.8	693.7	4572.8
2 PM	650.6	4564.3	675.4	4553.1	702.4	4551.8
1 PM	642.7	4544.6	675.6	4531.9	710.5	4532.3
NOON	632.4	4532.2	673.8	4515.9	717.7	4517.8
11 AM	622.4	4528.4	668.5	4506.5	719.7	4507.2
10 AM	614.6	4528.3	662.6	4501.4	718.5	4499.6
9 AM	606.0	4530.2	654.2	4498.6	712.7	4492.9
8 AM	594.8	4534.8	642.3	4500.3	700.7	4491.5

HOURLY SUMMARY OF METEOROLOGY

LDT	AVERAGE WIND SPEED (KILOMETERS PER HOUR)	RESULTANT WIND SPEED (KILOMETERS PER HOUR)	RESULTANT WIND DIRECTION	THETA
8-9 PM	0.0	0.0	0	0
7-8 PM	0.0	0.0	0	0
6-7 PM	0.0	0.0	0	0
5-6 PM	0.0	0.0	0	0
4-5 PM	32.8	31.9	207	13
3-4 PM	27.8	25.1	195	26
2-3 PM	24.7	22.7	181	23
1-2 PM	22.8	21.2	180	22
12-1 PM	19.3	16.2	186	33
11-12 AM	14.0	10.7	209	40
10-11 AM	10.1	7.8	229	40
9-10 AM	10.3	8.8	251	31
8-9 AM	12.5	12.1	278	14

FIGURE A-4

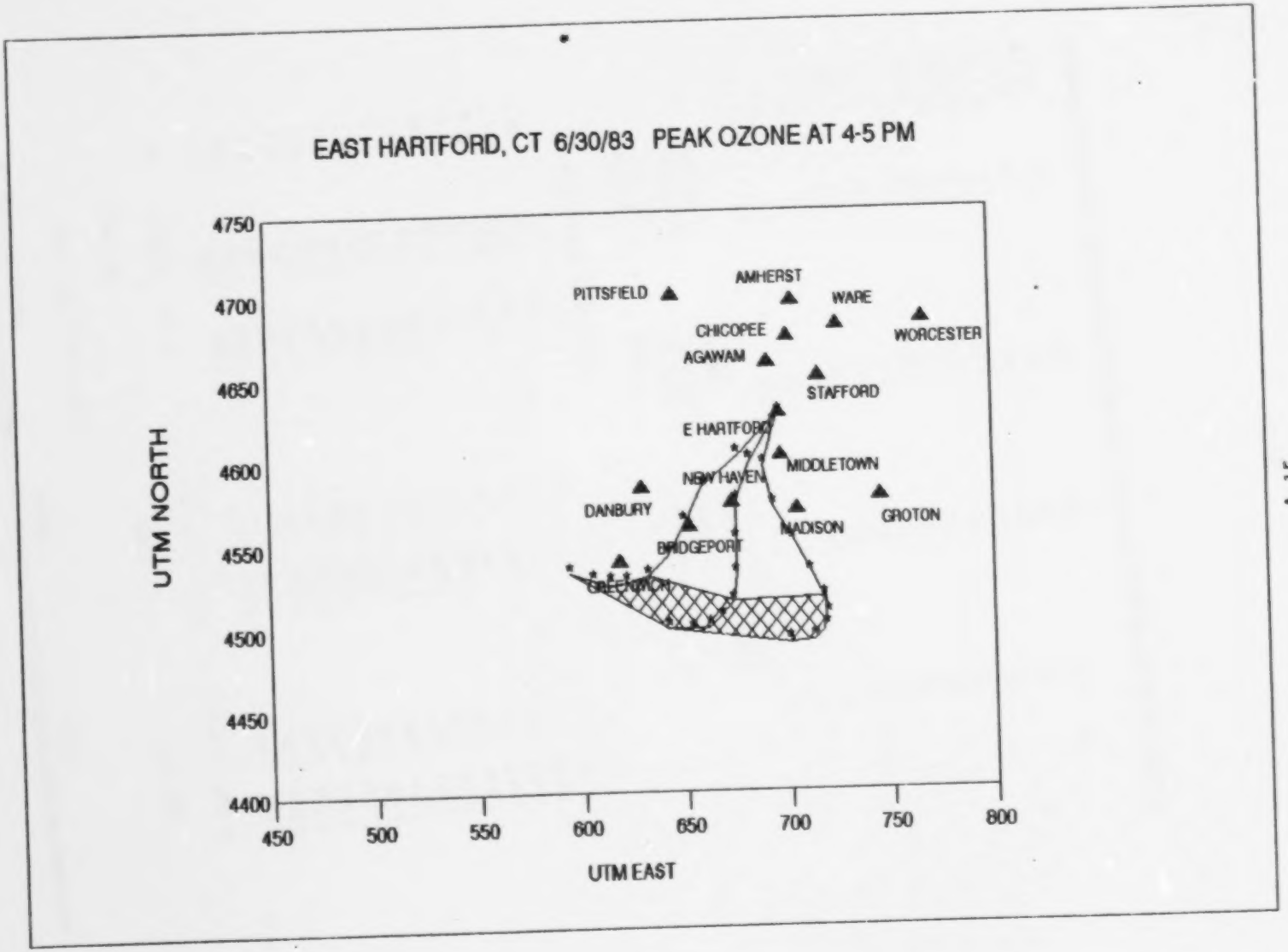

EAST HARTFORD, CT 6/30/83 PEAK OZONE AT 4-5 PM
UTM NORTH
4750
4700
4650
4600
4550
4500
4450
4400
450
500
550
600
650
700
750
800
UTM EAST
PITTSFIELD
AMHERST
WARE
CHICOPEE
WORCESTER
AGAWAM
STAFFORD
E HARTFORD
MIDDLETOWN
NEW HAVEN
DANBURY
GROTON
MADISON
BRIDGEPORT
GREENWICH

TABLE A-5

RESULTS SECTION ### AGANAN 6/30/83

HOURLY LOCATION OF AIR PARCEL

	LEFT EDGE		CENTER		RIGHT EDGE	
LST	X (UTM E)	Y(UTM N)	X (UTM E)	Y (UTM N)	X (UTM E)	Y(UTM N)
9 PM	692.1	4659.0	692.1	4659.0	692.1	4659.0
8 PM	692.1	4659.0	692.1	4659.0	692.1	4659.0
7 PM	692.1	4659.0	692.1	4659.0	692.1	4659.0
6 PM	692.1	4659.0	692.1	4659.0	692.1	4659.0
5 PM	672.4	4633.6	676.9	4630.6	681.8	4628.5
4 PM	651.6	4609.7	662.8	4602.3	675.3	4597.6
3 PM	635.9	4590.3	657.1	4578.0	680.8	4573.2
2 PM	626.9	4569.2	656.8	4555.1	689.2	4551.8
1 PM	619.3	4549.0	656.6	4533.5	696.5	4531.5
NOON	607.9	4537.0	653.3	4517.3	702.2	4516.0
11 AM	597.1	4533.4	646.7	4508.0	702.4	4504.6
10 AM	588.6	4534.1	639.5	4503.5	699.4	4496.7
9 AM	579.4	4536.4	630.2	4501.3	692.1	4490.5
8 AM	566.7	4540.3	617.1	4503.2	678.9	4490.4

HOURLY SUMMARY OF METEOROLOGY

LST	AVERAGE WIND SPEED (KILOMETERS PER HOUR)	RESULTANT WIND SPEED (KILOMETERS PER HOUR)	RESULTANT WIND DIRECTION	THETA
8-9 PM	0.0	0.0	0	0
7-8 PM	0.0	0.0	0	0
6-7 PM	0.0	0.0	0	0
5-6 PM	32.7	32.2	208	10
4-5 PM	32.7	31.6	206	15
3-4 PM	27.8	25.0	193	26
2-3 PM	24.8	22.9	181	22
1-2 PM	23.0	21.6	180	20
12-1 PM	19.3	16.6	192	32
11-12 AM	14.2	11.4	215	37
10-11 AM	10.6	8.4	238	37
9-10 AM	10.7	9.6	257	27
8-9 AM	13.4	13.2	278	9

FIGURE A-5

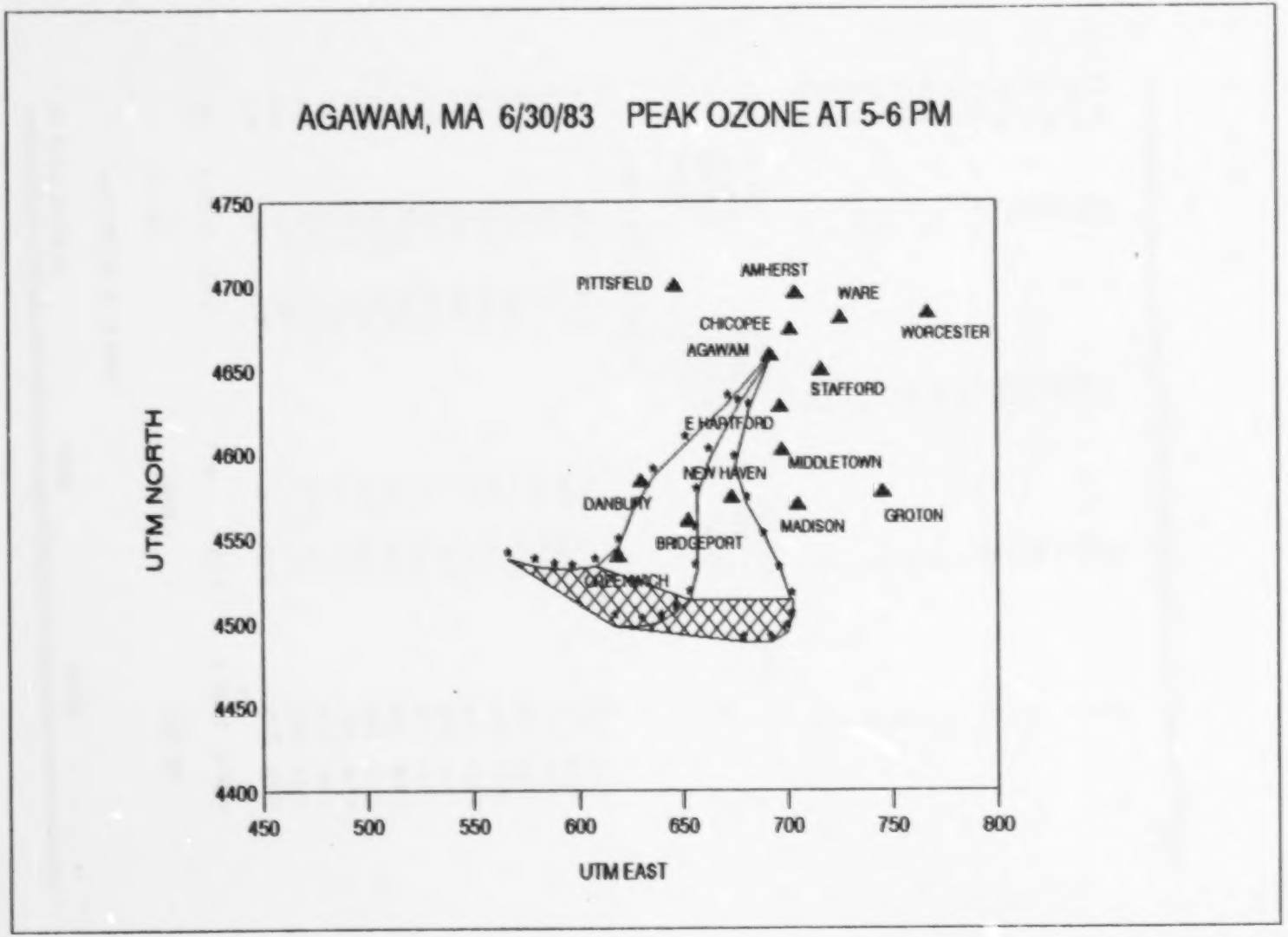

AGAWAM, MA 6/30/83 PEAK OZONE AT 5-6 PM
UTM NORTH
4750
4700
4650
4600
4550
4500
4450
4400
450
500
550
600
650
700
750
800
UTM EAST
PITTSFIELD
AMHERST
WARE
CHICOPEE
WORCESTER
AGAWAM
STAFFORD
E HARTFORD
MIDDLETOWN
NEW HAVEN
DANBURY
GROTON
MADISON
BRIDGEPORT
GREENWICH

TABLE A-6

RESULTS SECTION ### AMHERST 8/26/83

HOURLY LOCATION OF AIR PARCEL

LDT	LEFT EDGE X (UTM E)	LEFT EDGE Y(UTM M)	CENTER X (UTM E)	CENTER Y (UTM M)	RIGHT EDGE X (UTM E)	RIGHT EDGE Y(UTM M)
9 PM	704.3	4696.1	704.3	4696.1	704.3	4696.1
8 PM	704.3	4696.1	704.3	4696.1	704.3	4696.1
7 PM	704.3	4696.1	704.3	4696.1	704.3	4696.1
6 PM	704.3	4696.1	704.3	4696.1	704.3	4696.1
5 PM	704.3	4696.1	704.3	4696.1	704.3	4696.1
4 PM	704.3	4696.1	704.3	4696.1	704.3	4696.1
3 PM	704.3	4696.1	704.3	4696.1	704.3	4696.1
2 PM	704.3	4696.1	704.3	4696.1	704.3	4696.1
1 PM	680.2	4684.8	685.2	4677.5	692.3	4672.3
NOON	658.4	4669.0	668.3	4656.7	681.3	4647.8
11 AM	642.5	4650.1	658.3	4634.1	678.1	4623.3
10 AM	626.9	4631.9	650.4	4611.4	679.0	4599.3
9 AM	609.7	4619.3	640.6	4592.5	678.6	4578.0
8 AM	593.4	4613.0	629.7	4578.8	676.1	4560.7

HOURLY SUMMARY OF METEOROLOGY

LDT	AVERAGE WIND SPEED (KILOMETERS PER HOUR)	RESULTANT WIND SPEED (KILOMETERS PER HOUR)	RESULTANT WIND DIRECTION	THETA
8-9 PM	0.0	0.0	0	0
7-8 PM	0.0	0.0	0	0
6-7 PM	0.0	0.0	0	0
5-6 PM	0.0	0.0	0	0
4-5 PM	0.0	0.0	0	0
3-4 PM	0.0	0.0	0	0
2-3 PM	0.0	0.0	0	0
1-2 PM	28.1	26.6	226	19
12-1 PM	27.8	26.9	219	15
11-12 AM	25.7	24.7	204	16
10-11 AM	25.9	24.1	199	21
9-10 AM	23.7	21.2	207	26
8-9 AM	20.3	17.5	218	30

FIGURE A-6

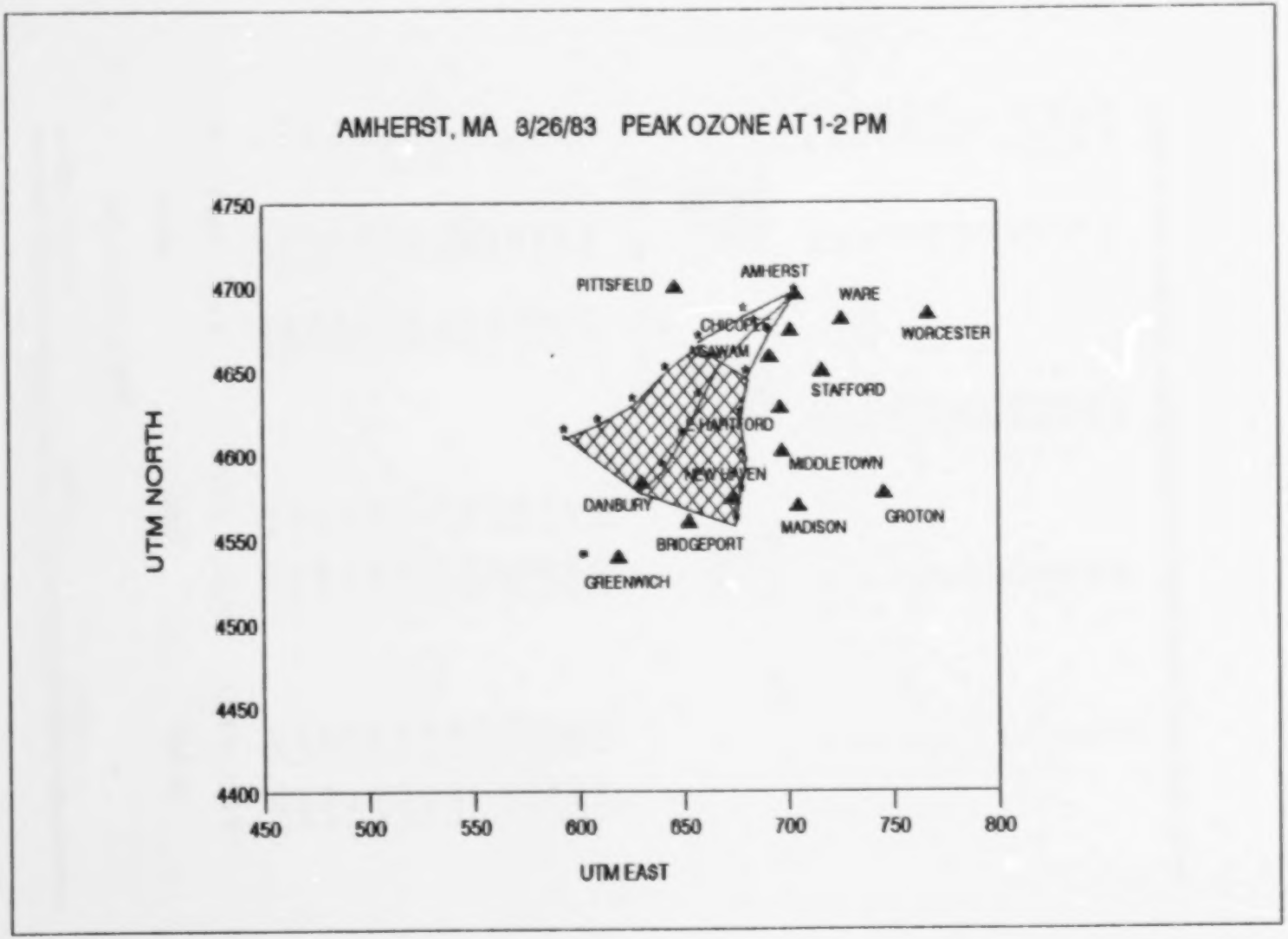

AMHERST, MA 8/26/83 PEAK OZONE AT 1-2 PM
UTM NORTH
4750
4700
4650
4600
4550
4500
4450
4400
450
500
550
600
650
700
750
800
UTM EAST
PITTSFIELD
AMHERST
WARE
WORCESTER
STAFFORD
MIDDLETOWN
GROTON
MADISON
NEW HAVEN
BRIDGEPORT
DANBURY
GREENWICH

TABLE A-7

RESULTS SECTION ### CHICOPEE 9/26/83

HOURLY LOCATION OF AIR PARCEL

	LEFT EDGE		CENTER		RIGHT EDGE	
LST	X (UTM E)	Y(UTM N)	X (UTM E)	Y (UTM N)	X (UTM E)	Y(UTM N)
9 PM	701.8	4674.0	701.8	4674.0	701.8	4674.0
8 PM	701.8	4674.0	701.8	4674.0	701.8	4674.0
7 PM	701.8	4674.0	701.8	4674.0	701.8	4674.0
6 PM	701.8	4674.0	701.8	4674.0	701.8	4674.0
5 PM	682.0	4657.0	686.0	4653.3	690.7	4650.4
4 PM	662.5	4637.2	668.3	4631.8	674.9	4627.5
3 PM	641.4	4618.1	650.9	4609.3	661.8	4602.2
2 PM	617.0	4602.4	631.8	4587.5	649.5	4576.0
1 PM	593.0	4585.2	613.0	4564.8	637.6	4549.3
NOON	568.8	4569.3	592.5	4544.1	621.2	4524.9
11 AM	541.7	4550.8	568.8	4527.5	602.1	4503.1
10 AM	516.5	4545.8	547.2	4509.0	585.5	4480.0
9 AM	496.2	4533.9	530.3	4492.6	572.8	4460.2
8 AM	479.0	4528.2	515.5	4482.2	561.8	4445.9

HOURLY SUMMARY OF METEOROLOGY

LST	AVERAGE WIND SPEED (KILOMETERS PER HOUR)	RESULTANT WIND SPEED (KILOMETERS PER HOUR)	RESULTANT WIND DIRECTION	THETA
8-9 PM	0.0	0.0	0	0
7-8 PM	0.0	0.0	0	0
6-7 PM	0.0	0.0	0	0
5-6 PM	26.7	26.1	217	12
4-5 PM	27.9	27.8	220	5
3-4 PM	28.9	28.5	218	10
2-3 PM	30.2	29.0	221	16
1-2 PM	30.5	29.5	220	15
12-1 PM	29.7	29.0	225	12
11-12 AM	29.8	29.0	235	14
10-11 AM	29.2	28.4	229	14
9-10 AM	24.2	23.6	226	14
8-9 AM	18.9	18.1	235	17

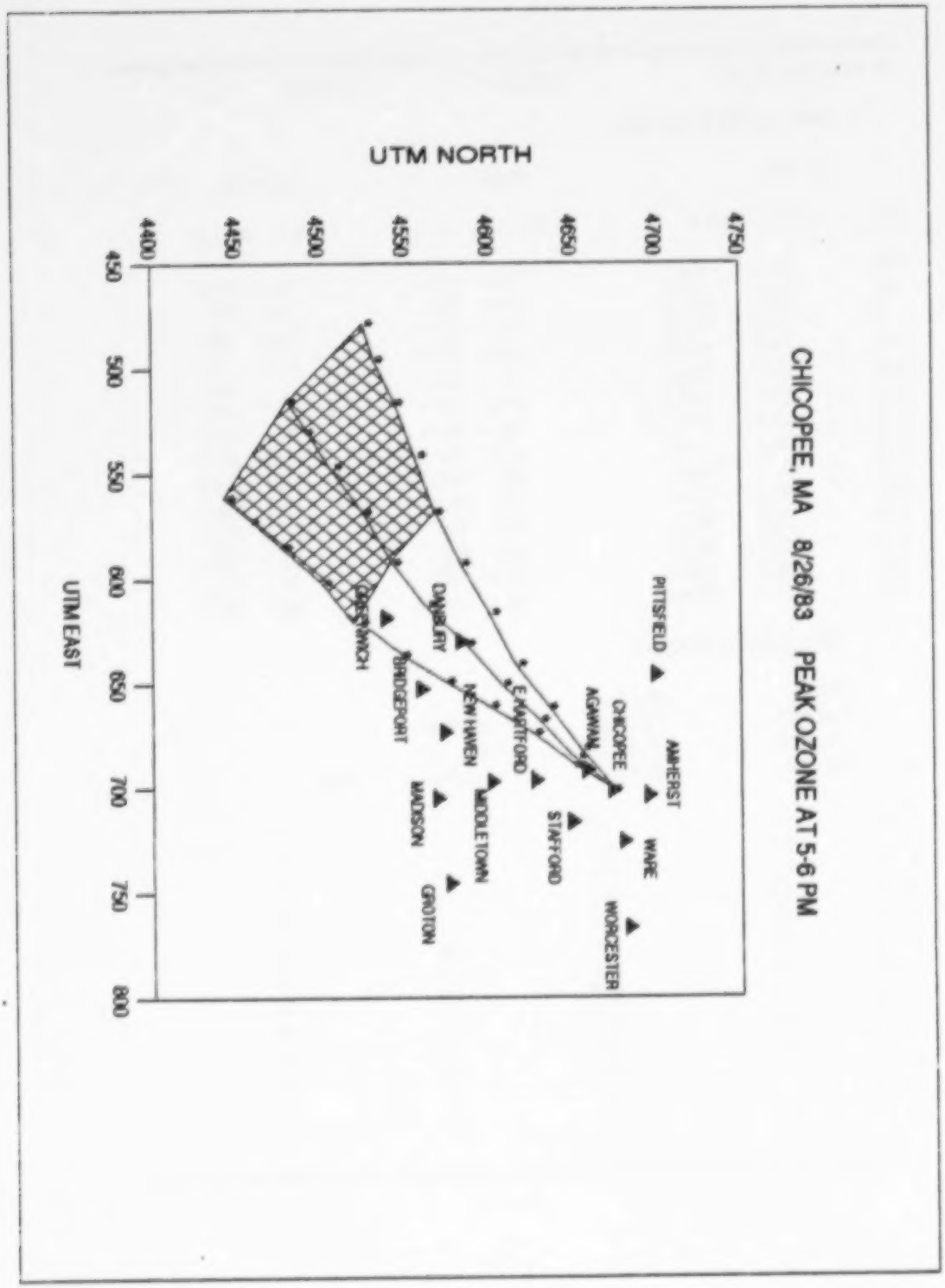

CHICOPEE, MA 8/26/83 PEAK OZONE AT 5-6 PM
UTM NORTH
4750
4700
4650
4600
4550
4500
4450
4400
450
500
550
600
650
700
750
800
UTM EAST
PITTSFIELD
AMHERST
CHICOPEE
AGAWAM
WARE
WORCESTER
E. HARTFORD
STAFFORD
DANBURY
NEW HAVEN
MIDDLETOWN
BRIDGEPORT
MADISON
GROTON

FIGURE A-7

TABLE A-8

*** RESULTS SECTION *** STAFFORD 8/26/83

HOURLY LOCATION OF AIR PARCEL

	LEFT EDGE		CENTER		RIGHT EDGE	
LST	X (UTM E)	Y(UTM N)	X (UTM E)	Y (UTM N)	X (UTM E)	Y(UTM N)
9 PM	716.5	4650.2	716.5	4650.2	716.5	4650.2
8 PM	716.5	4650.2	716.5	4650.2	716.5	4650.2
7 PM	716.5	4650.2	716.5	4650.2	716.5	4650.2
6 PM	716.5	4650.2	716.5	4650.2	716.5	4650.2
5 PM	716.5	4650.2	716.5	4650.2	716.5	4650.2
4 PM	695.6	4631.8	699.6	4628.0	704.3	4625.2
3 PM	675.0	4612.5	681.9	4606.0	690.0	4600.8
2 PM	650.5	4597.7	662.2	4585.3	676.2	4575.7
1 PM	626.2	4581.7	643.1	4563.3	663.9	4549.4
NOON	602.0	4566.1	623.4	4542.4	649.6	4524.3
11 AM	575.9	4557.3	600.7	4526.7	632.3	4502.9
10 AM	549.5	4547.9	576.7	4512.3	611.6	4484.1
9 AM	528.9	4534.8	559.0	4495.5	597.5	4464.2
8 AM	512.1	4526.5	544.0	4484.2	584.9	4450.3

HOURLY SUMMARY OF METEOROLOGY

LST	AVERAGE WIND SPEED (KILOMETERS PER HOUR)	RESULTANT WIND SPEED (KILOMETERS PER HOUR)	RESULTANT WIND DIRECTION	THETA
8-9 PM	0.0	0.0	0	0
7-8 PM	0.0	0.0	0	0
6-7 PM	0.0	0.0	0	0
5-6 PM	0.0	0.0	0	0
4-5 PM	28.4	27.9	217	11
3-4 PM	28.5	28.2	219	8
2-3 PM	29.6	28.6	224	15
1-2 PM	30.2	29.1	221	16
12-1 PM	29.6	28.8	223	14
11-12 AM	28.7	27.5	235	16
10-11 AM	28.6	28.0	239	11
9-10 AM	24.9	24.4	226	11
8-9 AM	19.1	18.8	233	11

FIGURE A-8

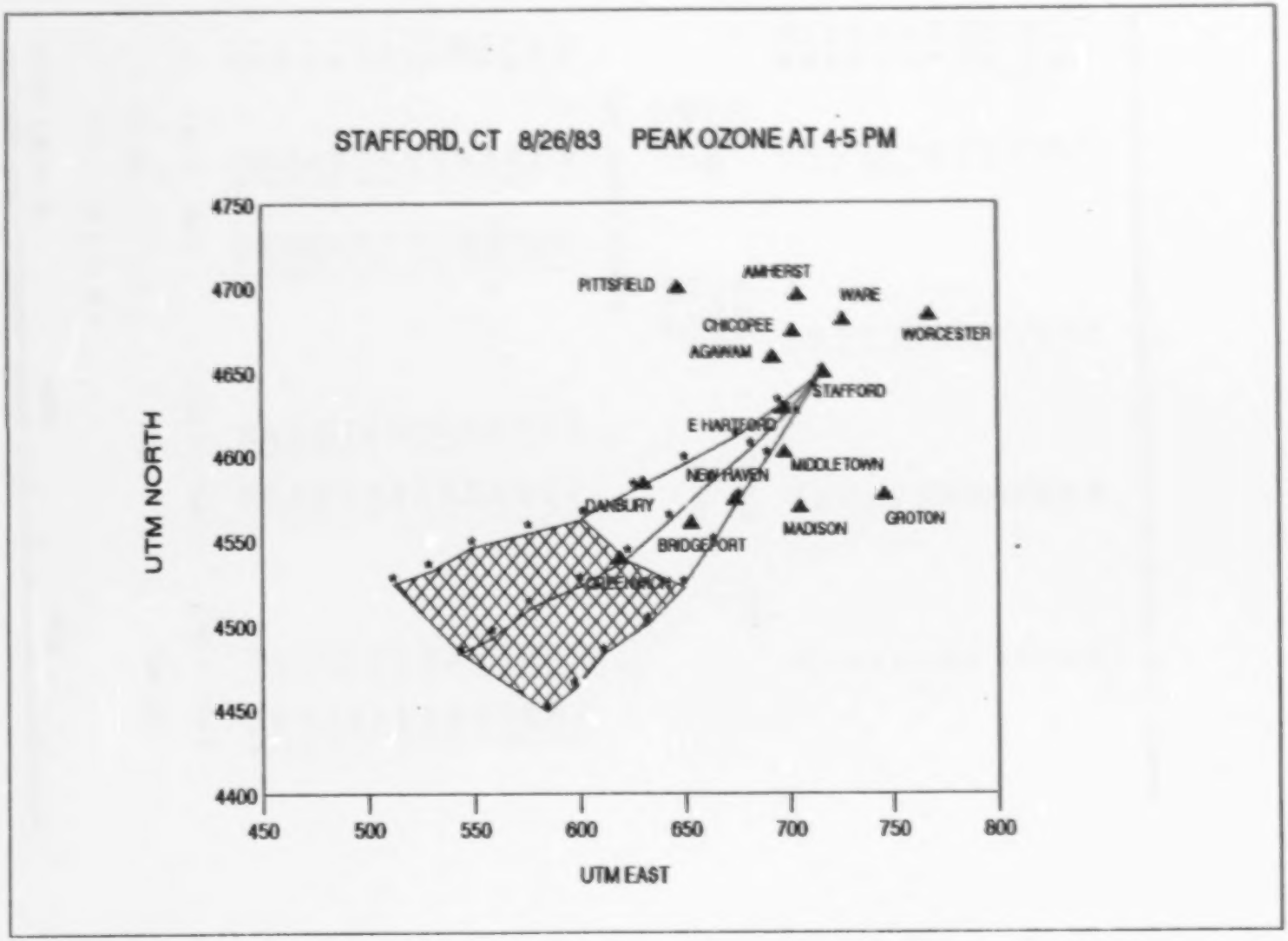

STAFFORD, CT 8/26/83 PEAK OZONE AT 4-5 PM
UTM NORTH
4750
4700
4650
4600
4550
4500
4450
4400
450
500
550
600
650
700
750
800
UTM EAST
PITTSFIELD
AMHERST
WARE
CHICOPEE
WORCESTER
AGAWAM
STAFFORD
E HARTFORD
MIDDLETOWN
NEW HAVEN
DANBURY
MADISON
GROTON
BRIDGEPORT

TABLE A-9

*** RESULTS SECTION *** AGANAM 8/8/83

HOURLY LOCATION OF AIR PARCEL

	LEFT EDGE		CENTER		RIGHT EDGE	
LST	X (UTM E)	Y(UTM N)	X (UTM E)	Y (UTM N)	X (UTM E)	Y(UTM N)
9 PM	692.1	4639.0	692.1	4639.0	692.1	4639.0
8 PM	686.3	4637.8	690.9	4637.1	695.4	4637.3
7 PM	684.1	4613.0	690.6	4612.2	697.2	4612.5
6 PM	670.4	4590.9	680.8	4588.1	691.6	4587.6
5 PM	647.9	4571.7	664.2	4563.7	681.9	4559.1
4 PM	619.8	4555.1	644.6	4537.6	673.8	4527.5
3 PM	594.8	4533.8	627.7	4509.4	666.9	4495.4
2 PM	573.3	4514.3	616.0	4482.8	666.9	4466.4
1 PM	555.6	4495.6	606.9	4458.3	668.7	4440.2
NOON	532.5	4481.8	589.7	4438.2	658.5	4415.9
11 AM	509.9	4474.8	570.3	4424.8	643.9	4397.2
10 AM	489.9	4472.7	552.3	4415.7	630.5	4382.2
9 AM	473.5	4473.8	537.3	4409.6	620.3	4369.3
8 AM	463.5	4476.7	527.7	4405.1	615.1	4360.4

HOURLY SUMMARY OF METEOROLOGY

LST	AVERAGE WIND SPEED (KILOMETERS PER HOUR)	RESULTANT WIND SPEED (KILOMETERS PER HOUR)	RESULTANT WIND DIRECTION	THETA
8-9 PM	22.4	22.0	183	12
7-8 PM	25.0	24.9	181	5
6-7 PM	26.4	26.0	202	10
5-6 PM	30.6	29.5	214	15
4-5 PM	35.3	32.6	217	23
3-4 PM	34.7	32.9	211	19
2-3 PM	31.7	29.0	204	24
1-2 PM	28.7	26.2	200	24
12-1 PM	27.7	26.4	221	18
11-12 AM	24.8	23.7	235	17
10-11 AM	21.6	20.1	243	21
9-10 AM	18.6	16.4	246	28
8-9 AM	13.1	10.3	240	38

FIGURE A-9

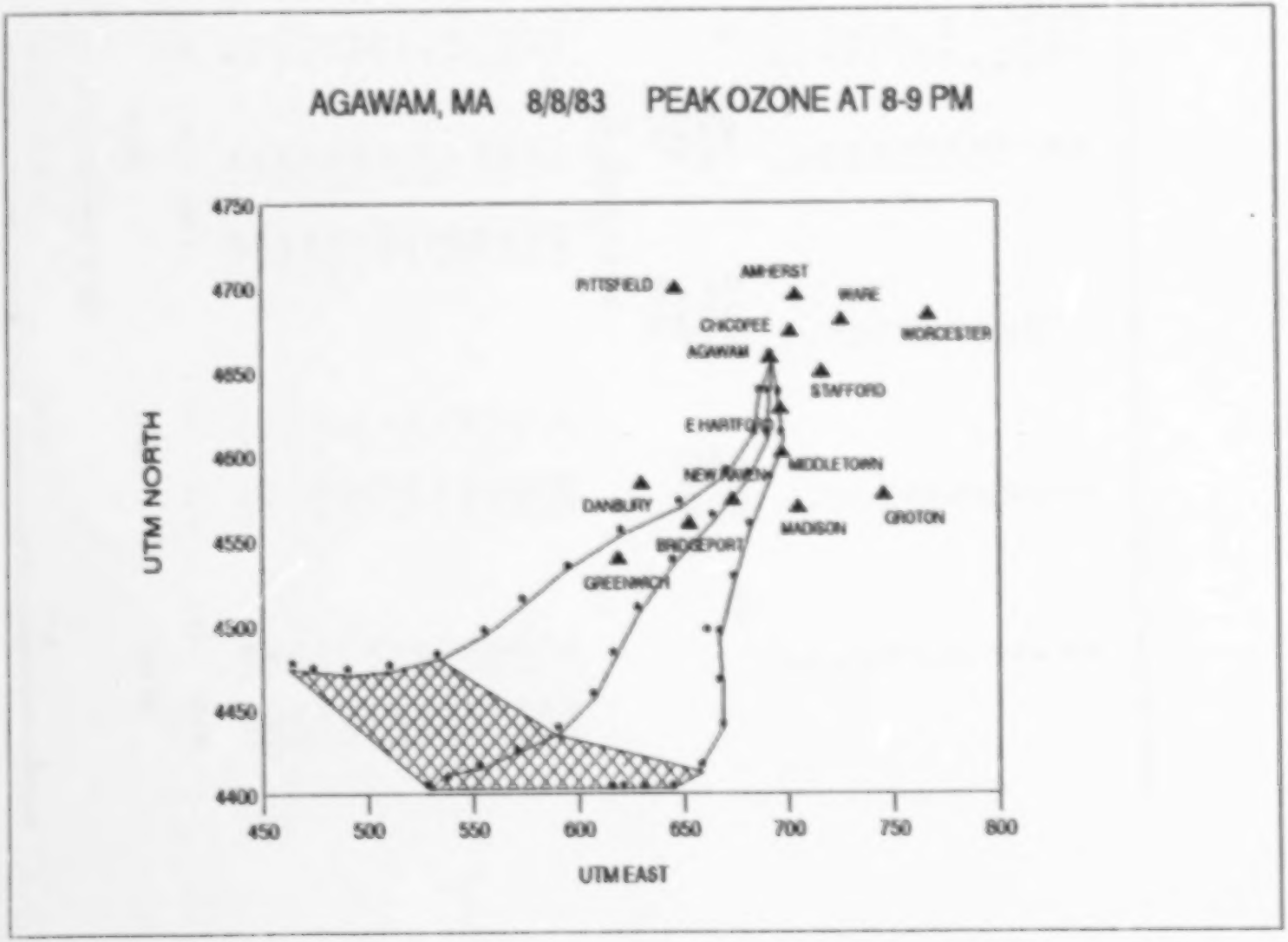

AGAWAM, MA 8/8/83 PEAK OZONE AT 8-9 PM
UTM NORTH
4750
4700
4650
4600
4550
4500
4450
4400
450
500
550
600
650
700
750
800
UTM EAST
PITTSFIELD
AMHERST
WARE
CHICOPEE
WORCESTER
AGAWAM
STAFFORD
E HARTFORD
MIDDLETOWN
NEW HAVEN
DANBURY
MADISON
GROTON
BRIDGEPORT
GREENWICH

TABLE A-10

*** RESULTS SECTION *** E HARTFORD 8/8/83

HOURLY LOCATION OF AIR PARCEL

	LEFT EDGE		CENTER		RIGHT EDGE	
LST	X (UTM E)	Y(UTM N)	X (UTM E)	Y (UTM N)	X (UTM E)	Y(UTM N)
9 PM	696.9	4628.5	696.9	4628.5	696.9	4628.5
8 PM	696.9	4628.5	696.9	4628.5	696.9	4628.5
7 PM	696.9	4628.5	696.9	4628.5	696.9	4628.5
6 PM	685.4	4605.8	687.8	4604.8	690.3	4604.0
5 PM	663.4	4587.3	670.7	4581.6	679.1	4577.5
4 PM	634.7	4574.2	649.8	4558.0	669.4	4547.4
3 PM	608.0	4555.7	631.2	4531.4	661.3	4516.0
2 PM	583.2	4538.1	615.3	4505.5	656.9	4485.9
1 PM	567.0	4517.5	608.0	4480.4	659.5	4459.9
NOON	547.5	4502.3	593.9	4460.0	652.0	4436.2
11 AM	525.6	4494.9	574.8	4447.0	637.2	4418.5
10 AM	505.6	4492.2	556.6	4438.2	622.6	4404.3
9 AM	488.9	4493.1	541.2	4431.7	611.7	4392.8
8 AM	478.8	4496.0	531.4	4428.0	605.9	4383.1

HOURLY SUMMARY OF METEOROLOGY

LST	AVERAGE WIND SPEED (KILOMETERS PER HOUR)	RESULTANT WIND SPEED (KILOMETERS PER HOUR)	RESULTANT WIND DIRECTION	THETA
8-9 PM	0.0	0.0	0	0
7-8 PM	0.0	0.0	0	0
6-7 PM	23.5	23.4	201	6
5-6 PM	29.6	28.8	216	14
4-5 PM	34.5	31.6	222	24
3-4 PM	34.7	32.5	213	21
2-3 PM	33.5	30.4	211	23
1-2 PM	28.2	26.1	196	22
12-1 PM	26.0	24.8	213	17
11-12 AM	24.0	23.1	234	16
10-11 AM	21.3	20.2	244	18
9-10 AM	18.6	16.7	247	26
8-9 AM	13.1	10.5	249	37

FIGURE A-10

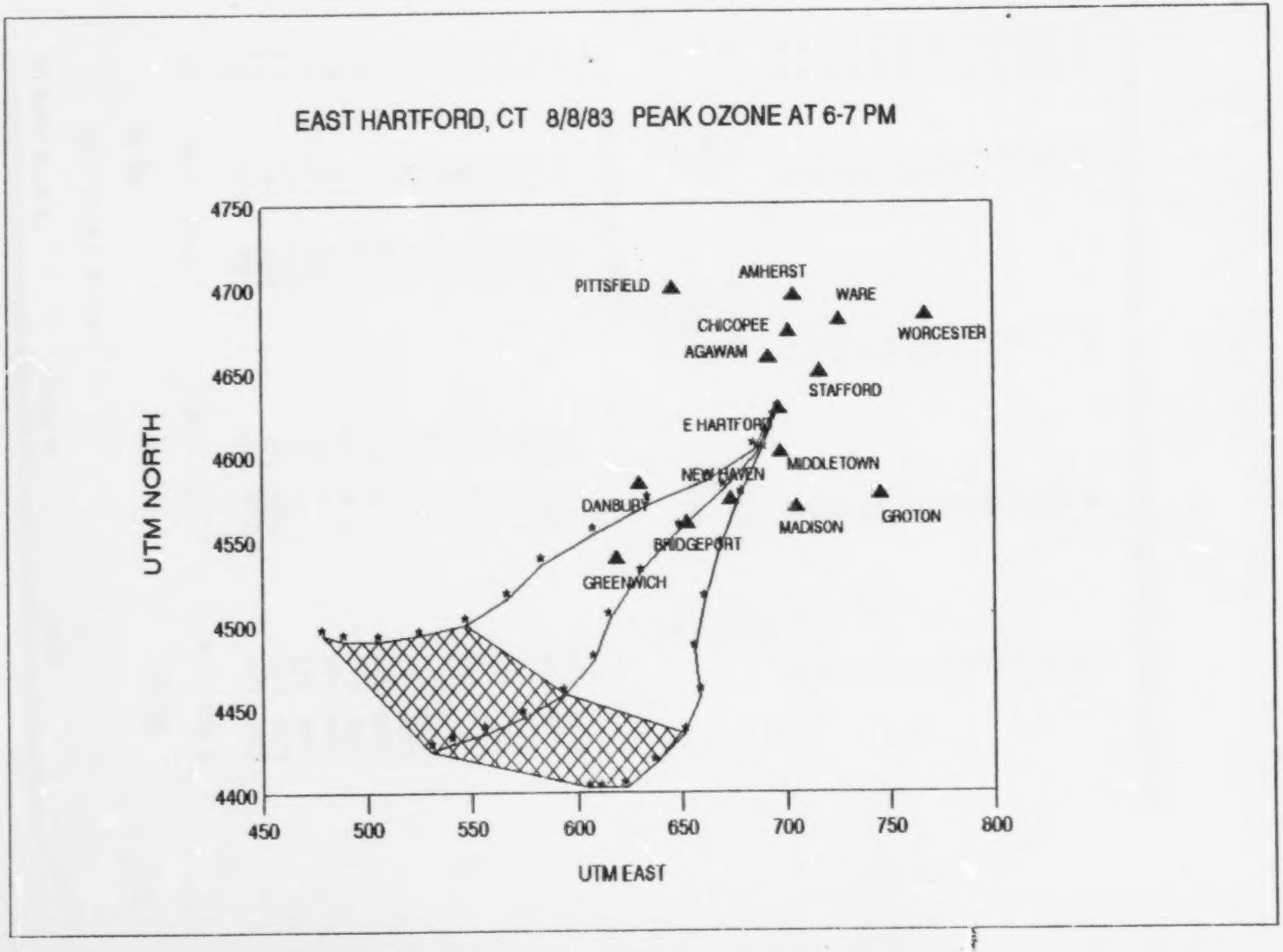

EAST HARTFORD, CT 8/8/83 PEAK OZONE AT 6-7 PM
UTM NORTH
UTM EAST
4750
4700
4650
4600
4550
4500
4450
4400
450
500
550
600
650
700
750
800
PITTSFIELD
AMHERST
WARE
CHICOPEE
WORCESTER
AGAWAM
STAFFORD
E HARTFORD
MIDDLETOWN
NEW HAVEN
DANBURY
MADISON
GROTON
BRIDGEPORT
GREENWICH

TABLE A-11

RESULTS SECTION ### STAFFORD 7/29/83

HOURLY LOCATION OF AIR PARCEL

	LEFT EDGE		CENTER		RIGHT EDGE	
LDT	X (UTM E)	Y(UTM N)	X (UTM E)	Y (UTM N)	X (UTM E)	Y(UTM N)
9 PM	716.5	4650.2	716.5	4650.2	716.5	4650.2
8 PM	716.5	4650.2	716.5	4650.2	716.5	4650.2
7 PM	716.5	4650.2	716.5	4650.2	716.5	4650.2
6 PM	716.5	4650.2	716.5	4650.2	716.5	4650.2
5 PM	716.5	4650.2	716.5	4650.2	716.5	4650.2
4 PM	716.5	4650.2	716.5	4650.2	716.5	4650.2
3 PM	716.5	4650.2	716.5	4650.2	716.5	4650.2
2 PM	691.9	4634.9	696.2	4629.5	701.7	4625.3
1 PM	663.9	4624.1	671.1	4613.1	680.6	4604.0
NOON	638.2	4608.4	650.8	4590.8	667.3	4576.9
11 AM	613.6	4590.8	632.3	4566.9	656.4	4548.7
10 AM	585.8	4575.7	610.7	4543.8	643.2	4520.0
9 AM	557.7	4559.1	587.6	4520.8	626.6	4491.9
8 AM	527.5	4544.5	559.0	4503.4	599.7	4471.8

HOURLY SUMMARY OF METEOROLOGY

LDT	AVERAGE WIND SPEED (KILOMETERS PER HOUR)	RESULTANT WIND SPEED (KILOMETERS PER HOUR)	RESULTANT WIND DIRECTION	THETA
8-9 PM	0.0	0.0	0	0
7-8 PM	0.0	0.0	0	0
6-7 PM	0.0	0.0	0	0
5-6 PM	0.0	0.0	0	0
4-5 PM	0.0	0.0	0	0
3-4 PM	0.0	0.0	0	0
2-3 PM	29.9	29.0	224	14
1-2 PM	30.6	30.0	237	12
12-1 PM	31.4	30.1	222	16
11-12 AM	31.5	30.2	218	17
10-11 AM	33.3	31.6	223	18
9-10 AM	33.7	32.6	225	14
8-9 AM	33.7	33.5	239	6

FIGURE A-11

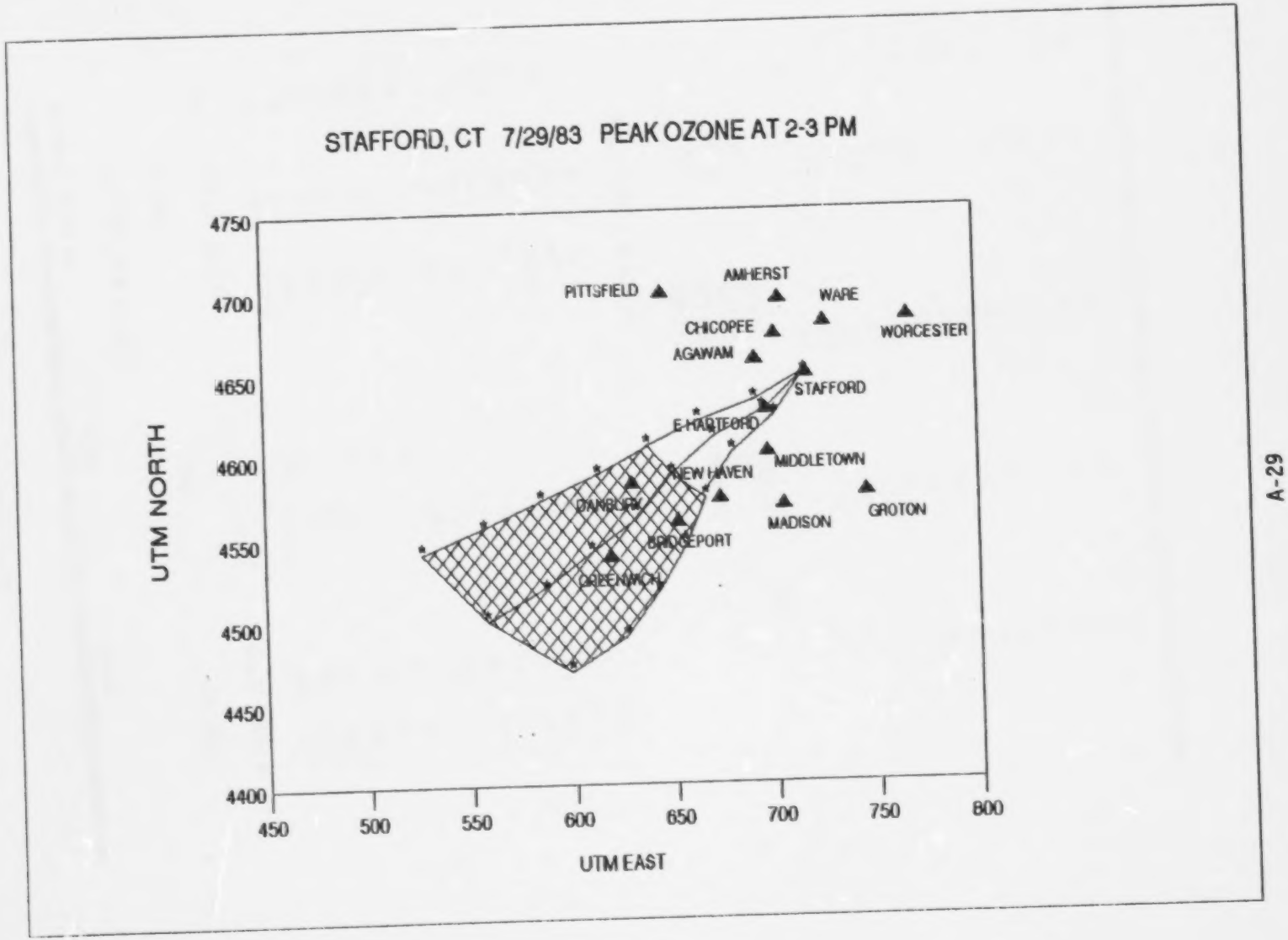

STAFFORD, CT 7/29/83 PEAK OZONE AT 2-3 PM
UTM NORTH
4750
4700
4650
4600
4550
4500
4450
4400
450
500
550
600
650
700
750
800
UTM EAST
PITTSFIELD
AMHERST
WARE
WORCESTER
CHICOPEE
AGAWAM
STAFFORD
E.HARTFORD
MIDDLETOWN
NEW HAVEN
DANBURY
GROTON
MADISON
BRIDGEPORT
GREENWICH

TABLE A-12

RESULTS SECTION

AGAWAM

7/29/83

HOURLY LOCATION OF AIR PARCEL

LDT	LEFT EDGE X (UTM E)	LEFT EDGE Y(UTM N)	CENTER X (UTM E)	CENTER Y (UTM N)	RIGHT EDGE X (UTM E)	RIGHT EDGE Y(UTM N)
9 PM	692.1	4659.0	692.1	4659.0	692.1	4659.0
8 PM	692.1	4659.0	692.1	4659.0	692.1	4659.0
7 PM	692.1	4659.0	692.1	4659.0	692.1	4659.0
6 PM	692.1	4659.0	692.1	4659.0	692.1	4659.0
5 PM	692.1	4659.0	692.1	4659.0	692.1	4659.0
4 PM	677.0	4626.9	680.1	4625.7	683.3	4624.7
3 PM	657.0	4600.5	664.9	4596.2	673.4	4593.1
2 PM	631.8	4581.1	648.3	4569.1	667.4	4561.8
1 PM	605.1	4559.2	632.1	4538.6	664.4	4527.4
NOON	579.3	4533.4	616.3	4505.7	660.2	4491.2
11 AM	558.7	4510.2	603.6	4477.3	656.8	4460.3
10 AM	534.9	4494.8	587.4	4454.2	650.5	4432.7
9 AM	508.3	4480.3	566.0	4432.6	636.1	4406.0
8 AM	483.4	4469.5	544.5	4416.2	619.1	4384.9

HOURLY SUMMARY OF METEOROLOGY

LDT	AVERAGE WIND SPEED (KILOMETERS PER HOUR)	RESULTANT WIND SPEED (KILOMETERS PER HOUR)	RESULTANT WIND DIRECTION	THETA
8-9 PM	0.0	0.0	0	0
7-8 PM	0.0	0.0	0	0
6-7 PM	0.0	0.0	0	0
5-6 PM	0.0	0.0	0	0
4-5 PM	35.7	35.5	200	5
3-4 PM	33.6	33.1	207	10
2-3 PM	34.0	31.8	212	21
1-2 PM	37.5	34.5	208	23
12-1 PM	38.6	36.5	206	19
11-12 AM	32.6	31.1	204	18
10-11 AM	30.5	28.3	215	22
9-10 AM	31.6	30.3	225	17
8-9 AM	27.9	27.1	233	14

FIGURE A-12

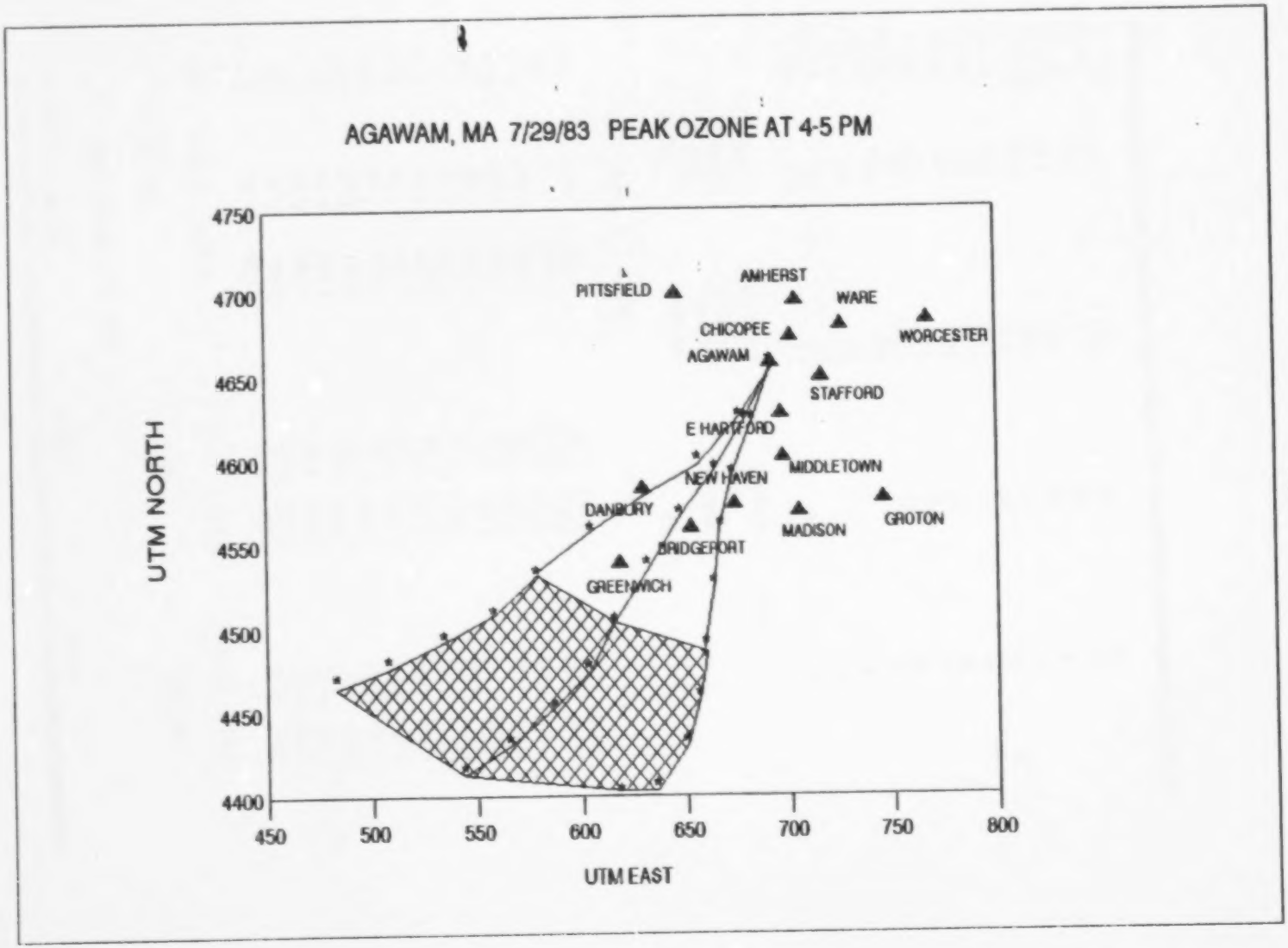

AGAWAM, MA 7/29/83 PEAK OZONE AT 4-5 PM
UTM NORTH
4750
4700
4650
4600
4550
4500
4450
4400
450
500
550
600
650
700
750
800
UTM EAST
PITTSFIELD
AMHERST
WARE
WORCESTER
CHICOPEE
AGAWAM
STAFFORD
E HARTFORD
MIDDLETOWN
NEW HAVEN
DANBURY
GROTON
MADISON
BRIDGEPORT
GREENWICH

TABLE A-13

RESULTS SECTION ### CHICOPEE 7/29/83

HOURLY LOCATION OF AIR PARCEL

LDT	LEFT EDGE X (UTM E)	LEFT EDGE Y(UTM N)	CENTER X (UTM E)	CENTER Y (UTM N)	RIGHT EDGE X (UTM E)	RIGHT EDGE Y(UTM N)
9 PM	701.8	4674.0	701.8	4674.0	701.8	4674.0
8 PM	701.8	4674.0	701.8	4674.0	701.8	4674.0
7 PM	701.8	4674.0	701.8	4674.0	701.8	4674.0
6 PM	701.8	4674.0	701.8	4674.0	701.8	4674.0
5 PM	701.8	4674.0	701.8	4674.0	701.8	4674.0
4 PM	685.0	4645.7	690.3	4643.1	696.0	4641.6
3 PM	667.7	4617.1	673.6	4614.2	680.0	4612.4
2 PM	642.0	4600.9	654.2	4590.8	668.7	4584.1
1 PM	614.8	4584.2	636.2	4564.5	663.1	4552.7
NOON	588.3	4561.4	618.9	4534.0	657.1	4518.2
11 AM	560.1	4539.9	598.4	4505.2	646.0	4484.6
10 AM	538.5	4522.6	584.3	4481.4	641.2	4457.3
9 AM	511.4	4506.3	562.3	4460.0	626.1	4430.6
8 AM	485.9	4497.0	539.6	4443.8	607.2	4410.1

HOURLY SUMMARY OF METEOROLOGY

LDT	AVERAGE WIND SPEED (KILOMETERS PER HOUR)	RESULTANT WIND SPEED (KILOMETERS PER HOUR)	RESULTANT WIND DIRECTION	THETA
8-9 PM	0.0	0.0	0	0
7-8 PM	0.0	0.0	0	0
6-7 PM	0.0	0.0	0	0
5-6 PM	0.0	0.0	0	0
4-5 PM	33.5	32.9	200	10
3-4 PM	33.4	33.4	210	1
2-3 PM	32.0	30.4	220	18
1-2 PM	35.0	31.9	214	24
12-1 PM	37.2	35.0	210	20
11-12 AM	37.0	35.4	216	17
10-11 AM	29.6	27.7	211	21
9-10 AM	32.0	30.7	226	16
8-9 AM	28.5	27.9	235	12

FIGURE A-13

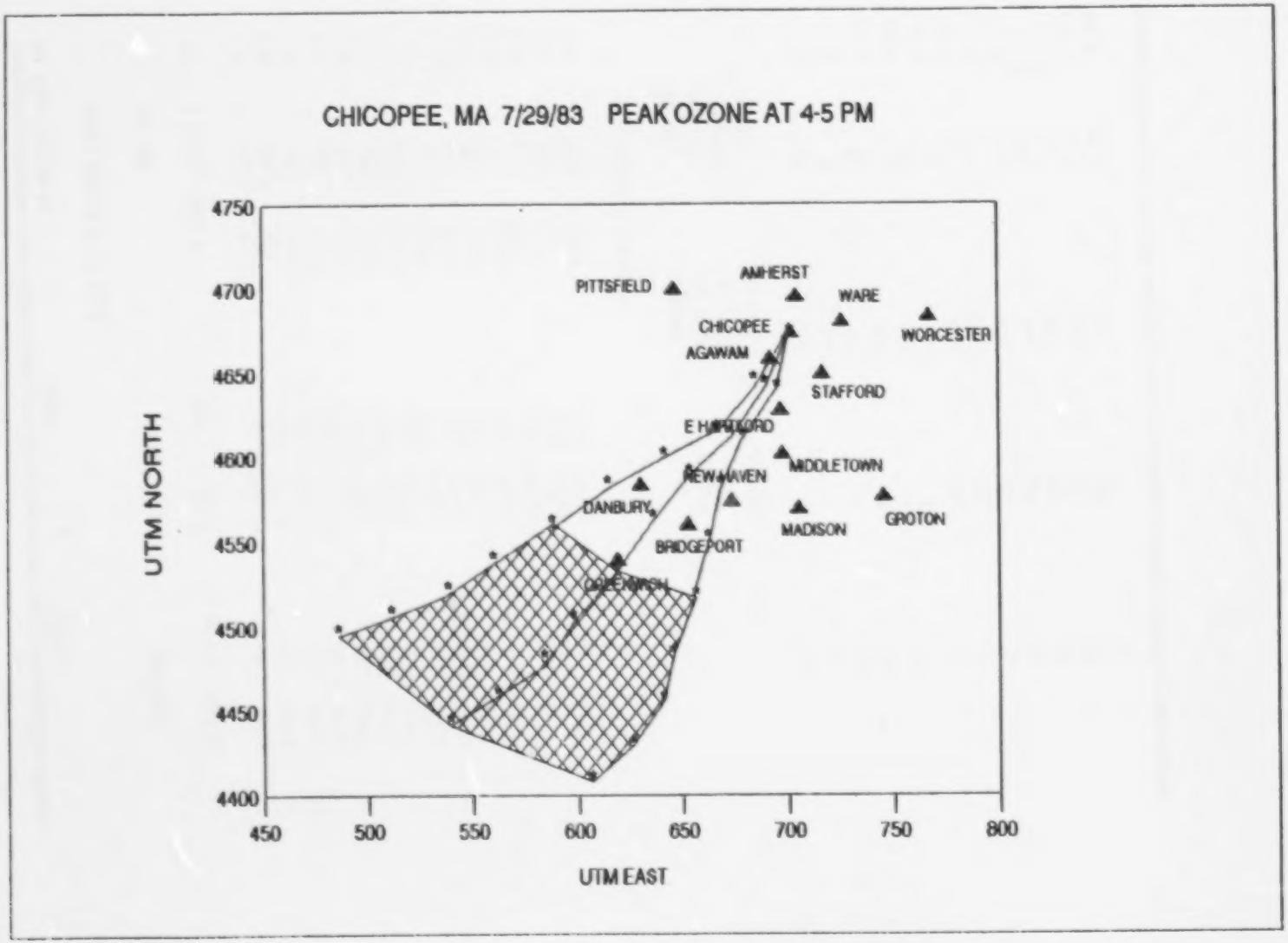

CHICOPEE, MA 7/29/83 PEAK OZONE AT 4-5 PM
UTM NORTH
4750
4700
4650
4600
4550
4500
4450
4400
450
500
550
600
650
700
750
800
UTM EAST
PITTSFIELD
AMHERST
WARE
WORCESTER
CHICOPEE
AGAWAM
STAFFORD
E HARTFORD
MIDDLETOWN
NEW HAVEN
DANBURY
BRIDGEPORT
MADISON
GROTON

TABLE A-14

$$$ RESULTS SECTION $$$ AGAWAM 6/27/83

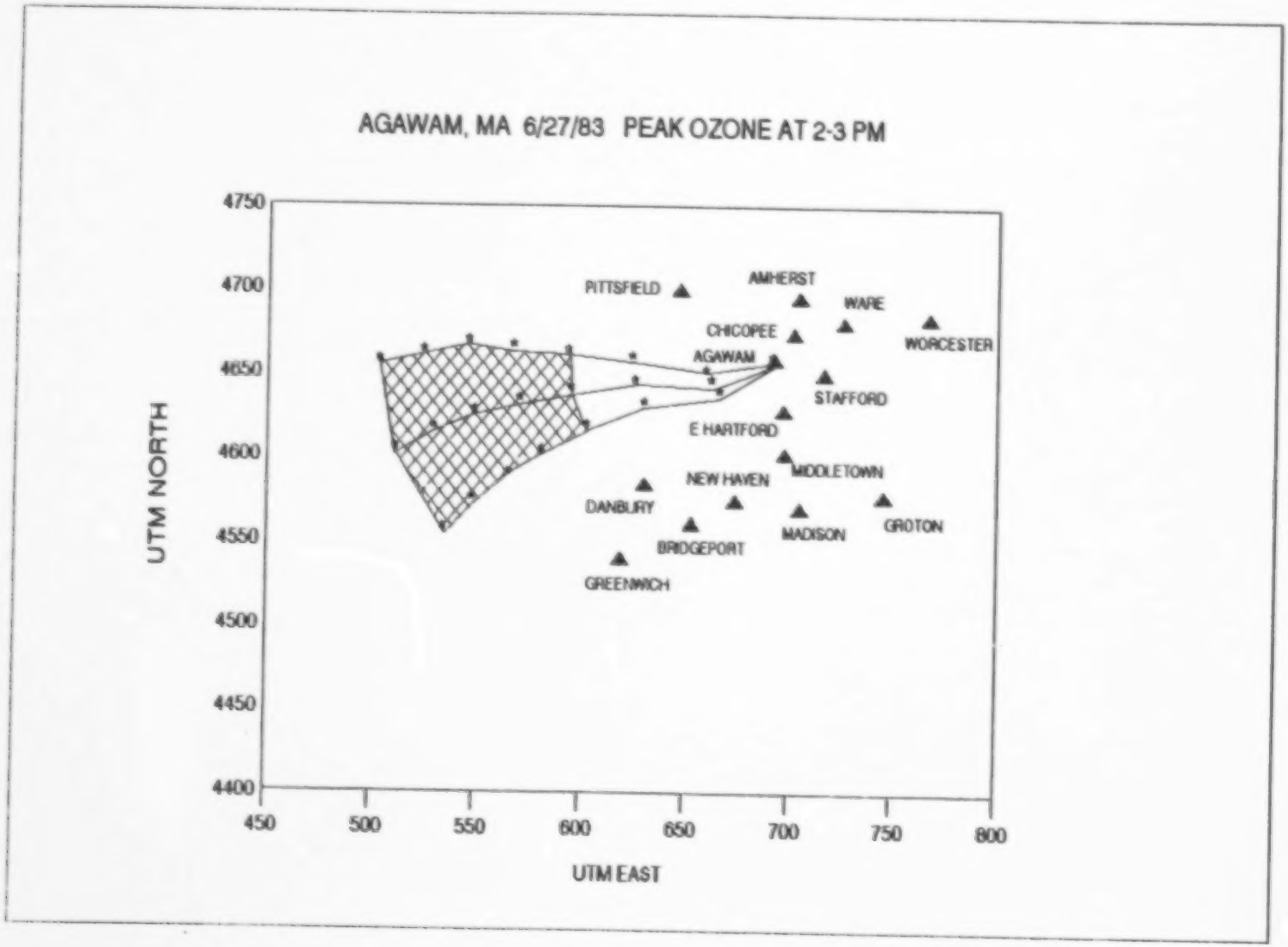
HOURLY LOCATION OF AIR PARCEL

	LEFT EDGE		CENTER		RIGHT EDGE	
LDT	X (UTM E)	Y(UTM N)	X (UTM E)	Y (UTM N)	X (UTM E)	Y(UTM N)
9 PM	692.1	4659.0	692.1	4659.0	692.1	4659.0
8 PM	692.1	4659.0	692.1	4659.0	692.1	4659.0
7 PM	692.1	4659.0	692.1	4659.0	692.1	4659.0
6 PM	692.1	4659.0	692.1	4659.0	692.1	4659.0
5 PM	692.1	4659.0	692.1	4659.0	692.1	4659.0
4 PM	692.1	4659.0	692.1	4659.0	692.1	4659.0
3 PM	692.1	4659.0	692.1	4659.0	692.1	4659.0
2 PM	660.5	4650.9	663.0	4644.3	666.9	4638.3
1 PM	624.4	4659.2	626.0	4645.0	630.5	4631.4
NOON	593.8	4663.0	595.6	4640.1	602.7	4618.2
11 AM	568.1	4665.2	570.6	4633.4	581.5	4603.5
10 AM	546.7	4668.3	549.9	4627.2	565.3	4589.1
9 AM	525.1	4662.2	530.3	4616.4	548.6	4574.2
8 AM	504.0	4656.6	512.0	4604.4	535.1	4557.0

HOURLY SUMMARY OF METEOROLOGY

LDT	AVERAGE WIND SPEED (KILOMETERS PER HOUR)	RESULTANT WIND SPEED (KILOMETERS PER HOUR)	RESULTANT WIND DIRECTION	THETA
8-9 PM	0.0	0.0	0	0
7-8 PM	0.0	0.0	0	0
6-7 PM	0.0	0.0	0	0
5-6 PM	0.0	0.0	0	0
4-5 PM	0.0	0.0	0	0
3-4 PM	0.0	0.0	0	0
2-3 PM	33.4	32.6	243	13
1-2 PM	37.9	37.1	271	12
12-1 PM	32.0	30.8	261	16
11-12 AM	27.5	25.8	255	20
10-11 AM	23.9	21.7	253	25
9-10 AM	23.0	22.4	241	13
8-9 AM	23.0	21.9	237	18

FIGURE A-14


AGAWAM, MA 6/27/83 PEAK OZONE AT 2-3 PM
UTM NORTH
4750
4700
4650
4600
4550
4500
4450
4400
450
500
550
600
650
700
750
800
UTM EAST
PITTSFIELD
AMHERST
WARE
CHICOPEE
WORCESTER
AGAWAM
STAFFORD
E HARTFORD
MIDDLETOWN
NEW HAVEN
DANBURY
MADISON
GROTON
BRIDGEPORT
GREENWICH

APPENDIX B

SOURCES OF HOURLY SURFACE WIND DATA

Surface wind data may be obtained by contacting the National Climatic Data Center (NCDC), Federal Building, Asheville, North Carolina 28801. Data tapes containing "surface airways observations" are assigned the code, TD-1440. Wind direction data are available for 36 points of the compass, wind speed is entered in knots. National Weather Service sites with archived hourly data are listed in Table A-1.

TABLE B-1. CLASS 1 NWS WEATHER STATIONS WITH HOURLY DATA

State	City	Other Name	Station Number
Alabama	Birmingham		13876
	Huntsville	Madison	13856
	Mobile	Bates	13894
	Montgomery	Dannelly	13895
Alaska	Anchorage		26451
	Annette Island		25308
	Barter Island		27401
	Bethel		26615
	Betiles		26533
	Big Delta	Allen	26415
	Cold Bay		25624
	Fairbanks		26411
	Gulkana	Interm	26425
	Homer		25507
	Juneau		25309
	Kodiak		25501
	McGrath		26510
	Naknek		25503
	Nome		26617
	Point Barrow	W. Rogers W. Post	27502
	St. Paul Island		25713
	Talkeetna		26528
	Valdez		26442
	Yakutat	State	25339
Arizona	Flagstaff	Pullian	03103
	Phoenix	Sky Harbor	23183
	Tucson		23160
	Prescott (FAA operated)		23184
Arkansas	Ft. Smith		13964
	Little Rock	Adams	13963
California	Bakersfield	Meadows	23155
	Bishop		23157
	Fresno	Hammer	93194
	Los Angeles		23174
	Mt. Shasta		24215
	Red Bluff		24216
	Sacramento (FAA operated)	Executive	23232
	San Bernardino	County Airport	23161
	San Diego	Lindbergh	23188
	San Francisco		23234
	Santa Maria	Public	23273

TABLE B-1. CLASS 1 NWS WEATHER STATIONS WITH HOURLY DATA (Cont'd)

State	City	Other Name	Station Number
Colorado	Alamosa		23061
	Colorado Springs	Peterson	93037
	Denver	Stapleton	23062
	Eagle (FAA operated)	County Airport	23063
	Grand Junction	Walker	23066
Connecticut	Hartford	Bradley	14752
Delaware	Wilmington	Greater Wilm. AP	13781
District of Columbia	Washington	National	13743
Florida	Apalachicola		12832
	Daytona Beach		12834
	Ft. Myers	Page	12835
	Jacksonville		13889
	Key West		12836
	Miami		12839
	Orlando (FAA operated)	Jet Port	12815
	Pensacola	Hagler	13899
	Tallahassee		93805
	Tampa		12842
	West Palm Beach	Palm Beach	12844
Georgia	Atlanta		13874
	Augusta	Bush	3820
	Columbus		93842
	Macon	Lewis B. Wilson	3813
	Savannah	Travis	3822
Hawaii	Hilo	Lyman Field	21504
	Honolulu	John Rogers	22521
	Kahului		22516
	Lihue		22536
Idaho	Boise		24131
	Lewiston	Nez Perce County	24149
	Pocatello		24156
Illinois	Chicago	O'Hare	94846
	Moline	Quad City	14823
	Peoria	Greater Peoria	14842
	Rockford	Greater Rockford	94822
	Springfield	Capital	93822

TABLE B-1. CLASS 1 NWS WEATHER STATIONS WITH HOURLY DATA (Cont'd)

State	City	Other Name	Station Number
Indiana	Evansville	Dress	93817
	Ft. Wayne	Baer	14827
	Indianapolis	Weir Cook	93819
	South Bend		14848
Iowa	Des Moines		14933
	Sioux City		14943
	Waterloo		94910
Kansas	Concordia	Blosser	13984
	Dodge City		13985
	Goodland	Renner	23065
	Russell (FAA operated)		93997
	Topeka	Billard	13996
	Wichita		3928
Kentucky	Lexington	Blue Grass	93820
	Louisville	Standtford	93821
Louisiana	Baton Rouge	Ryan	13970
	Lake Charles		3937
	New Orleans	Moisant	12916
	Shreveport		13957
Maine	Bangor	Dow	14606
	Caribou		14607
	Portland		14764
Maryland	Baltimore	Friendship	93721
Massachusetts	Boston	Logan	14739
	Worcester		94746
Michigan	Alpen	Phelps Collins	94849
	Detroit (FAA operated)	City	14822
	Detroit	Grand Haven	94847
	Flint	Bishop	14826
	Grand Rapids	Kent Co. Airport	94860
	Lansing	Capital City	14836
	Muskegon	County	14840
	Sault Ste. Marie		14847
	Traverse City (FAA operated)	Cherry Cap	14850

TABLE B-1. CLASS 1 NWS WEATHER STATIONS WITH HOURLY DATA (Cont'd)

State	City	Other Name	Station Number
Minnesota	Duluth		14913
	International Falls		14918
	Minneapolis	St. Paul	14922
	Rochester		14925
	St. Cloud	Whitney Mem.	14926
Mississippi	Jackson	Thompson	3940
	Meridian	Key	13865
Missouri	Columbia	Peg	3945
	Kansas City		3947
	Kansas City		13988
	Springfield		13995
	St. Louis	Lambert	13994
Montana	Billings	Logan	24033
	Butte	Silver Bow Cty Apt.	24135
	Glasgow		94008
	Havre	City County Arpt.	94012
	Helena		24144
	Kalispell	Glacier Natl. Park	24146
	Lewiston		24036
	Miles City (FAA operated)		24037
	Missoula	Johnson Bell	24153
Nebraska	Lincoln		14939
	Norfolk	Karl Stefan Mem.	14941
	North Platte	Lee Bird	24023
	Omaha	Eppley	14942
	Scottsbluff		24028
Nevada	Desert Rock		3160
	Elko		24121
	Ely	Yelland	23154
	Las Vegas	McCarran	23169
	Reno		23185
	Tonopah (FAA operated)		23153
	Winnemucca		24128
New Hampshire	Concord		14745
New Jersey	Atlantic City		93730
	Newark		14734

TABLE B-1. CLASS 1 NWS WEATHER STATIONS WITH HOURLY DATA (Cont'd)

State	City	Other Name	Station Number
New Mexico	Albuquerque	Kirtland	23050
	Clovis	Cannon	23009
	Farmington (FAA operated)		23090
	Roswell	Walker	23009
	Truth or Consequences	(FAA operated)	93045
New York	Albany	County AP	14735
	Binghampton	Broome Cty AP	4725
	Buffalo	Greater Buffalo AP	14733
	Massena	Richards	94725
	New York	JFK	94789
	New York	Laguardia	14732
	Rochester	Monroe Cty	14768
	Syracuse	C. E. Hancock	14771
North Carolina	Asheville		3812
	Cape Hatteras		93729
	Charlotte	Douglas	13881
	Greensboro	GSO-Hgh Pt. AP	13723
	Raleigh-Durham	RDU	13727
	Wilmington	New Hanover Cty AP	13748
North Dakota	Bismarck		24011
	Fargo	Hector Field	14914
	Minot		24013
	Williston	Sloulin	24014
Ohio	Akron		14895
	Cleveland	Hopkins AP	14820
	Columbus	Port Columbus	14821
	Dayton	JM Cox Day	93815
	Mansfield	Lamm	14891
	Toledo		94830
	Youngstown		14852
Oklahoma	Oklahoma City	Will Rogers	13967
	Tulsa		13968

TABLE B-1. CLASS 1 NWS WEATHER STATIONS WITH HOURLY DATA (Cont'd)

State	City	Other Name	Station Number
Oregon	Astoria	Clatsop Co. AP	94224
	Eugene	Mahlon Sweet AP	24221
	Medford		24225
	North Bend (FAA operated)		24284
	Pendleton		24155
	Portland		24229
	Redmond (FAA operated)		24230
	Salem		24232
	Sexton Summit		24236
Pennsylvania	Allentown		14737
	Bradford (FAA operated)	Regional AP	4751
	Erie	Port Erie	14860
	Harrisburg	State	14751
	Philadelphia		13739
	Pittsburgh		04823
	Wilkes Barre		14777
	Williamsport	Lycoming Cty.	14778
Rhode Island	Providence	Francis Green	14765
South Carolina	Charleston		13880
	Columbia		13883
	Greenville		3870
South Dakota	Huron	W.W. Howes	14936
	Pierre (FAA operated)		24025
	Rapid City		24090
	Sioux Falls	Foss	14944
Tennessee	Bristol	Tri-County Airport	13877
	Chattanooga	Lovell	13882
	Knoxville		13891
	Memphis		13893
	Nashville	Metro	13897
Texas	Abilene		13962
	Amarillo	English	23047
	Austin	Mueller	13958
	Brownsville	Rio Grande	12919
	Corpus Christi	Cliff Haus	12924
	El Paso		23044
	Ft. Roth	DFW Reg. AP	3927
	Houston	Int. Cont. AP	12960
	Lubbock	West Air Term.	23042
	Lufkin (FAA operated)	Angelina Co.	93987

TABLE B-1. CLASS 1 NWS WEATHER STATIONS WITH HOURLY DATA (Cont'd)

State	City	Other Name	Station Number
Texas	Midland	Sloan	23023
	Port Arthur	Jefferson Co.	12917
	San Angelo	Mathis	23034
	San Antonio		12921
	Victoria	Foster	12912
	Waco	Blackland	13959
	Wichita Falls		13966
Utah	Bryce Canyon (FAA operated)		23159
	Cedar City (FAA operated)		93129
	Milford		23176
	Salt Lake City		24127
Vermont	Burlington	Ethan Allen	14742
Virginia	Lynchburg		13733
	Norfolk		13737
	Richmond	Byrd AP	13740
	Roanoke		13741
	Wallops Island		93739
	Washington, DC	Dulles	93738
Washington	Olympia		24227
	Quillayute		94240
	Seattle	Tacoma	24233
	Spokane		24157
	Stampede Pass		24237
	Yakima		24243
West Virginia	Beckley		3872
	Charleston	Kanawha	13866
	Elkins	Randolph Co.	13729
	Huntington	Tri-State	3860
Wisconsin	Eau Claire (FAA operated)		14991
	Green Bay	Austin Strabel	14898
	La Crosse		14920
	Milwaukee	Mitchell	14839
Wyoming	Casper		24089
	Cheyenne		24018
	Lander	Hunt	24021
	Rock Springs		24027
	Sheridan	County	24029